Environmental management for vector control

Fourth report of the
WHO Expert Committee on Vector Biology
and Control

Technical Report Series
649

World Health Organization, Geneva 1980

842

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Geneva, 13–19 November 1979

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ENVIRONMENTAL MANAGEMENT FOR VECTOR CONTROL

Third Report of the WHO Expert Committee on Vector Biology and Control

The WHO Expert Committee on Vector Biology and Control met in Geneva from 13 to 19 November 1979. Dr J. Hamon, Director of the Division of Vector Biology and Control, opened the meeting on behalf of the Director-General. Dr Hamon pointed out that this was the first time that a meeting on this important subject had been convened. Environmental management had, in the past, constituted one of the main tools for the prevention and control of vectorborne diseases. For some time the technique had been relegated to a secondary place in vector control and, on occasions, completely disregarded. Only recently had it been recognized that this reliable method should be reintroduced and applied jointly with all other available procedures for preventing vectorborne diseases. Since the application of well-known measures of environmental management would have to be tested as to their suitability and feasibility under different ecological, epidemiological and socioeconomic conditions, the study of strategies and operational methods would be required before full use could be made of environmental management on a large scale.

1. INTRODUCTION

Vectorborne diseases have been among the most important worldwide health problems for many years and, despite progress made in their control[1] during the past decades by the use of specific chemicals, they still represent a constant and serious risk to the major part of the world's population. These diseases are often linked to poor socioeconomic conditions but some can be associated with projects aimed at economic development. Thus the construction of dams for power generation, irrigation, flood control and water supply

[1] Throughout this report the term "vector control" applies, in a broad sense, to measures used against primary and intermediate vertebrate and invertebrate hosts and animal reservoirs of human and animal diseases.

may lead to an increase in the prevalence of malaria, schistosomiasis and onchocerciasis, while human settlement may increase urban filariasis and domestic rodentborne diseases.

The task of the Expert Committee was to review the known measures which have been developed in the past for the control of many invertebrate and vertebrate hosts and vectors of human and animal diseases; to assess the present application of environmental management techniques in vector control programmes; to estimate the interaction of these measures with agriculture, irrigation and other socioeconomic development schemes; to establish principles for the planning, organization and evaluation of environmental management programmes for vector control; and to make proposals for training the requisite manpower, for organizing an efficient information system, and for conducting research in many areas where knowledge is insufficient, including cost-effectiveness analysis of proposed or future control techniques.

In view of the importance being given to environmental management measures, the Committee has formulated recommendations designed to improve the prevention and control of vectorborne diseases through the application of these measures.

2. BASIC CONSIDERATIONS

The Constitution of the World Health Organization defines health as a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity. This state of health can be achieved primarily through the adjustment of man to his physicochemical, biological and social environment. An understanding of the interrelationship, within the total environment, of vector, pathogen, and man is fundamental to the study of human communicable disease. Even with chronic diseases and injury, the influence of the environment is becoming more apparent, leading to possible preventive measures through management techniques which were so successfully applied to abate vectorborne diseases. The conquest of such diseases as malaria, plague and yellow fever in the developed world was primarily the result of a slow but steady organization of the environment for economic, commercial and social purposes, which, coincidentally, effected a dramatic reduction in the transmission of these diseases. On closer examination, it may be

demonstrated that many of the "environmental diseases" are man-induced and that human activities sometimes unwittingly alter and modify the vector habitats in such a way that vectorborne diseases are greatly intensified. Human endeavours must proceed, but in a manner that will avert adverse effects on health. Unfortunately, the rectification of existing problems is difficult and costly, so that attention should first be directed at incorporating preventive measures during the very early stages of any project.

2.1 Definitions

During the past five years or so, environmental management for vector control has been the subject of discussion in several papers prepared by WHO for presentation at various international meetings on malaria control, water resources development, and irrigation and agriculture. The term "environmental management" and some other related terms were defined in these papers, rather broadly to begin with, but later more precisely as their use became established.

To avoid unnecessary misunderstandings, it is important that these terms should be interpreted and used in the same way by all concerned with environmental management for vector control. The Expert Committee considered a number of commonly used terms and agreed on their definitions, which are given below.

(1) *Environmental management for vector control: The planning, organization, carrying out and monitoring of activities for the modification and/or manipulation of environmental factors or their interaction with man with a view to preventing or minimizing vector propagation and reducing man–vector–pathogen contact.*

This approach, which should be carried out prudently and skilfully, is naturalistic and involves an attempt to extend and intensify natural factors which limit vector breeding, survival and contact with man.

(2) *Environmental modification: A form of environmental management consisting in any physical transformation that is permanent or long-lasting of land, water and vegetation, aimed at preventing, eliminating or reducing the habitats of vectors without causing unduly adverse effects on the quality of the human environment.*

Environmental modification includes drainage, filling, land levelling and transformation of impoundment margins. Although

these measures are usually of a permanent nature, proper operation and adequate maintenance are essential for their effective functioning.

(3) *Environmental manipulation: A form of environmental management consisting in any planned recurrent activity aimed at producing temporary conditions unfavourable to the breeding of vectors in their habitats.*

Water salinity changes, stream flushing, regulation of the water level in reservoirs, vegetation removal, shading and exposure to sunlight are examples of environmental manipulation activities.

(4) *Modification or manipulation of human habitation or behaviour: A form of environmental management that reduces man–vector–pathogen contact.*

Examples of this kind of approach include the siting of settlements away from vector sources, mosquito- and rodent-proofing of houses, personal protection and hygiene measures against vectors, and provision of such installations as mechanical barriers and facilities for water supply, wastewater and excreta disposal, laundry, bathing and recreation to prevent or discourage human contact with infested waters.

2.2 Reconsideration of environmental management

Emphasis on environmental management for the control of vector and animal reservoirs of disease all but disappeared with the development of spectacular chemical control measures. New persistent and versatile pesticides were apparently so cost-effective that the eventual eradication of the important vectorborne diseases seemed in sight. Unfortunately, this goal was overoptimistic. First there were harmful effects on innocuous species, which were followed by the unexpected development of widespread resistance in the target vectors and then by public objection to repeated application of persistent chemicals. Magnification of trace amounts in the environment—particularly in the food-chain—gave rise to fear of chronic toxicity to man and animals or of severe disturbance in the balance of nature. The narrowing of the economic advantages of chemical control measures due to the recent increase in the cost of raw materials and energy is discouraging the use of repetitive chemical control and favours the consideration of other methods. Environ-

mental management measures offer an alternative approach, which may in the long run bring about lasting control of serious vectorborne diseases with no danger of toxicity or ecological impairment. These measures may prove to be less expensive over the long term and, moreover, produce considerable benefits to agriculture and socioeconomic development.

3. METHODS AND APPLICATIONS OF ENVIRONMENTAL MANAGEMENT

3.1 Environmental modification

Engineering works which greatly influence disease vector potential form part of large-scale undertakings such as irrigation systems, agricultural drainage, water impoundment for a variety of purposes, flood control, and highway and railroad construction. In the past and even today, the engineer has created vector problems by being unaware of the impact of his practices. Not only has vector breeding been promoted, but health problems have been greatly intensified through the presence of human carriers of disease in imported labour forces. In the Americas, the change in approach began in Panama, where, during the building of the Canal, environmental modification and sanitation became linked to large engineering projects, some of which are still functioning. Soon thereafter sanitary engineers became active in the construction, operation and maintenance of railroads, dams and reservoirs in the USA.

The concept of "species sanitation" narrowed the public health objective to reasonably attainable goals. Most vectors are quite fastidious in the selection of their habitat: aquatic forms select either fresh or brackish water, and there is little overlap in their choice. Some prefer lakes, others rivers, with distinctive degrees of shade, temperature, velocity, etc. In the past, many ponds have been drained in ignorance of the fact that the vector concerned preferred running water.

Identification of the vectors incriminated and proper study of their ecology would have permitted the delineation of specific areas in which control interventions were necessary and would have been effective. This implies that a team approach is required to attain the goal of vectorborne disease control.

3.1.1 *Drainage*

Drainage systems may consist of piped drains, open lined or unlined drains, subsoil drains, or vertical drains. Their removal of unwanted water, which will eliminate or restrict breeding places for disease vectors, is normally achieved through gravitational flow. Where this is impossible pumping is used. Such pumping requires energy and entails additional operational and maintenance requirements, which are reflected in considerable increases in costs.

3.1.1.1 *Urban and rural drainage.* The control of urban filariasis transmitted by infected water-breeding culicine mosquitos has been accomplished by providing good urban drainage. Such drainage will also reduce the breeding of other mosquito species, as well as that of snails. Sullage and rainwater accumulating in yards and in roadside ditches are best cleared by an organized piped drainage system, supplemented in some situations by open lined stormwater drains.

In rural situations, piped drainage systems may not be possible on account of cost. Consequently, the appropriate technology for use may be open drains or localized soakaways. Public and private water points should be served with suitable drainage for the removal of spillage. This may be relevant to both rural and certain urban areas.

3.1.1.2 *Agricultural and watershed drainage.* This is usually achieved through open channels, using natural stream courses and drainage lines, sometimes modified by canalization and embanking. In high-value land—for example, that used in intensive agriculture—the channels are usually artificial and generally unlined; where soil characteristics permit and cost is acceptable, piped subsoil drains may be used to prevent an excessive rise of the water-table from damaging the quality of the land and crop production.

While these measures frequently have a directly beneficial effect in the destruction of certain vector habitats, their improper design, operation and, in particular, maintenance may create suitable habitats for other vectors. For example, whereas swamp drainage may eliminate the breeding of certain mosquitos, the drains themselves may provide ideal habitats for other mosquitos or for snails.

The procedure of diking and dewatering has been widely used in agricultural drainage and for flood protection, with some incidental benefit for mosquito control. It was employed rather extensively for

mosquito control in the Kentucky Reservoir by the Tennessee Valley Authority in the USA. In general, this method is most applicable to large shallow areas in flooded plains. An advantage of dewatering such areas is the reclamation of fertile land suitable for agricultural use in the area dewatered. Pumping is often necessary to get rid of the volume of water in the diked area. The diking and dewatering method should be viewed in terms of its economic impact on agricultural returns and should not be judged primarily on its merits as a means of achieving mosquito control.

Water held on an impervious stratum overlying a pervious one may be removed by vertical drains, which are boreholes penetrating the impervious layer. As vertical drains may result in groundwater pollution, care must be taken in their construction and use.

Attention should be given to avoid creating an accumulation of water through construction activities. Spoil banks should be broken at intervals to ensure lateral drainage. Culvert pipes under roads should be kept clear to flow and not to create collections of stagnant water suited to the breeding of certain mosquito species. Undrained borrow pits should not be permitted.

A special aspect of watershed drainage is encountered in areas of coastal marshland, where, through the construction of channels and the operation of tidal gates, the salinity of the water can be manipulated to the detriment of target disease vectors.

3.1.2 *Filling*

Filling is one of the most satisfactory methods for the permanent elimination of mosquito- and snail-breeding depressions, provided a source of fill material is available without creating undrained borrow pits. Scattered and small water collections in or around villages and other settlements can be eliminated by hand-filling and grading by vector control staff. Many marshy areas can be filled with stable demolition waste and excavation materials. Refuse and other organic solid wastes may not be desirable as fill material, since they can cause considerable gasification and settlement of the fill. Depressions in coastal areas can be filled with hydraulic spoil from channel and harbour maintenance dredging.

3.1.2.1 *Filling and deepening.* Many vector species breed in shallow waters with emergent vegetation. Filling and deepening is a measure for reducing the extent of such habitats in permanent water bodies. Extensive shallow water can be eliminated by balanced cut

and fill. In this manner the shoreline can be considerably shortened and steepened below the depth tolerance of emergent plants. No loss in reservoir storage volume occurs as in complete filling, and maintenance is minimal provided side slopes are stable.

The technique is also applicable to fish-ponds, sewage lagoons, and stock-watering ponds.

3.1.2.2 *Topography alteration.* For the control of snail and mosquito breeding in irrigation fields, careful land grading must be done for both water application and drainage. Surface pools formed from residual irrigation water or rainfall constituting mosquito breeding sites can be eliminated in this way.

3.1.3 *Velocity alteration*

The Expert Committee discussed the importance of water velocity in canals and streams as a factor that may deter the breeding of the snail intermediate hosts of *Schistosoma* and the blackfly vectors of onchocerciasis. Since snails settle and multiply mainly in quiescent and slow-flowing waters, and blackfly larvae need a strong current to reach maturity, an increase in water velocity to dislodge snails[2] or a reduction in velocity to interrupt blackfly larval development[3] could substantially decrease the populations of these species. It was realized, however, that such a measure is, of course, inapplicable where both types of vector are present.

In new projects, branch canals and drains should be located as far as practicable on sloping ground and make the best use of the topographical gradient to maintain command of the land; where possible, they should be designed to convey water at the most convenient velocities for vector control. Canal lining offers the most practicable and effective means for increasing water velocities; it also decreases

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[2] According to a laboratory study, a velocity of 0.65 m/s at the top of the shell caused dislodgement of the snails from the surfaces of the Lucite laboratory flume. Laboratory-reared *Biomphalaria glabrata* were used in the study. (Jobin, W. R. & Ippen, A. T. Ecological design of irrigation canals for snail control. *Science*, **145**: 1324-1326 (1964).)

[3] According to field studies carried out in West Africa the larvae of *Simulium damnosum* can tolerate water velocities varying between 0.5 and 2.0 m/s under the best conditions of anchorage, food and aeration. The velocities most commonly tolerated range from 0.7 to 1.2 m/s. (Philippon, B. *L'onchocercose humaine en Afrique de l'Ouest*. Paris, ORSTOM, 1978. Initiations–Documentations techniques N° 37.)

seepage, reduces silting and obstructs the growth of rooted weeds. Regulating water gates in canals and temporary barriers can be used to dam watercourses to retard the flow of water in the upstream stretch and thus interfere with blackfly breeding.

3.2 Environmental manipulation

Proved methods of manipulation, including the control of pond-breeding malaria vectors in impounded water, are based on a sound knowledge of the ecology, or bionomics, of the vector, with particular regard to specific limiting factors. When different species of disease vectors are dealt with it is often difficult to devise a strategy of management using a common body of knowledge. Table 1 lists a number of vectorborne diseases, giving some general information on the reproductive potential and adult behaviour of the vectors concerned, and attempts to illustrate the disparities between the factors which in part determine the relative risk of disease transmission. Habitat and climate are known to be limiting factors in the distribution of vectorborne diseases, influencing not only the vector but the pathogen as well. Man's action and behaviour sometimes help to promote the maintenance and spread of disease and often counteract naturalistic controls by such activities as bringing water to deserts and reordering the regime or natural equilibrium of streams—all interfering with the forces of nature. Manipulation techniques, on the other hand, seek to capitalize on the natural factors unfavourable to the vector and to extend and intensify them.

A WHO Scientific Group on Vector Ecology (WHO Technical Report Series, No. 501, 1972) deliberated extensively on ecological studies which would provide dynamic data appropriate for constructing complex models of disease suitable for computer processing, systems analysis and simulation techniques. Among other uses, these models would allow the simulation of systems and the prediction of the effects of natural changes and man-made interventions in various situations.

The inputs for such models are far from complete for every vector, but include environmental factors, reproductive potential and host factors. At the present time a strong scientific base is often lacking. Therefore, environmental manipulation measures may have to be carried out case by case, utilizing past experiences in one area for application to another with similar vector habitats.

Table 1. Generalized biological information concerning the vectors of some diseases

Disease	Vector or intermediate host	Reproductive potential				Preferred behaviour			
		Number of eggs	Egg-to-egg cycle	Number of broods	Life-span	Feeding time	Resting place	Source of blood	Flight or dispersal range[a]
Malaria	*Anopheles* mosquitos	200	10-14 days	6-10	20 weeks	Night	Indoors and outdoors	Man and animals	1.5 km
Filariasis; viral diseases	*Culex* and *Aedes* mosquitos	200	8-10 days	6-10	20 weeks	Night and day	Indoors and outdoors	Man and animals	0.1-8 km
Onchocerciasis	Blackflies	400	2-3 weeks	3-4	1-2 weeks	Day	Outdoors	Man and animals	4-8 km
Infantile diarrhoea	Houseflies	150	7-14 days	2-3	3 weeks	Day	Indoors and outdoors	—	4 km
Schistosomiasis	Aquatic snails	45	30 days	10-12	50 weeks	—	Outdoors	—	10-30 m
African trypanosomiasis	Tsetse flies	1 pupa	60 days	10	3-12 weeks	Day	Outdoors	Man and animals	2-4 km
Leishmaniasis	Sandflies	50	6-8 weeks	2	12 weeks	Night	Outdoors	Man and animals	50 m
Chagas' disease	Triatomid bugs	200	52 weeks	1-2	50 weeks	Night	Indoors	Man	10-20 m
Plague	Rats	8 per litter	12 weeks	4	32 weeks	Night and day	Indoors and outdoors	—	50-80 m
	Fleas	12	8 weeks	10	15 weeks	Night and day	Indoors and outdoors	Animals and man	—

Note: The figures given are only indicative and illustrate the major factors affecting transmission. They vary widely from species to species and in different environments.

[a] Under normal, static conditions.

Many of the measures discussed briefly below have been successfully applied in one locale or another, but may require adaptation to meet conditions elsewhere. The two most commonly used manipulative measures are water management and vegetation control.

3.2.1 *Water management*

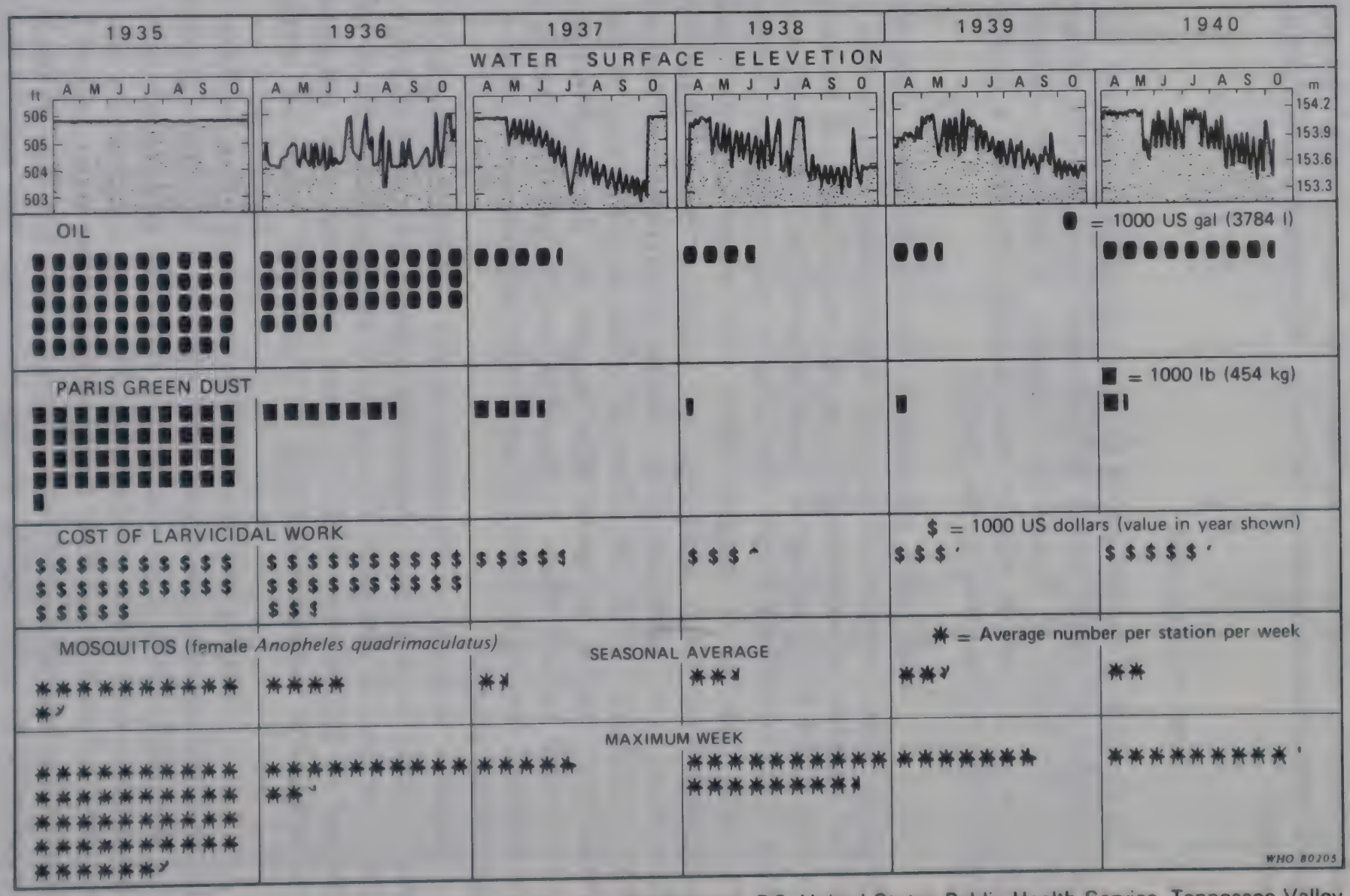
In the case of vectors which require aquatic environments for the propagation of either adults or immature forms, and in instances where the body of water—for example, a reservoir—cannot be eliminated, the habitat may be manipulated to maintain a biological imbalance unfavourable to the species.

3.2.1.1 *Water level fluctuation.* One of the great man-made health problems may arise from large impoundments, which give rise to vast numbers of pond-breeding mosquitos and snails. In the design of dams and the planning of reservoir operation, each project will have to be considered in the light of its primary purposes. Where it has been possible to integrate these with vector control, striking successes have been achieved, an example being water level fluctuation in the operation of the Wilson Reservoir of the Tennessee Valley Authority, USA, the effects of which are illustrated in Fig. 1. Preliminary studies in Puerto Rico suggest that the same technique may control aquatic snails. It should be noted that the effect of the fluctuations may be indirect, through their influence on vegetation in the aquatic margin.

Another example of fluctuation is the intermittent irrigation of paddy-fields for snail and anopheline control, where the increase in water use can be accepted. This practice has been reported to have resulted in higher crop yield in some areas, but may sometimes encourage the increased breeding of floodwater mosquito species.

3.2.1.2 *Sluicing and flushing.* In the case of a number of stream-breeding mosquitos and snail vectors, it has been observed that during the peak rainy season, the turbulent and muddy flow is not conducive to vector propagation. However, towards the end of the rains, when streams flow moderately and the water is cool and clear, vector-breeding conditions become ideal. The idea of flushing periodically to upset stable stream conditions has proved to be effective for *Anopheles minimus* and *A. maculatus* control.

Fig. 1. Mosquito control and water level fluctuation: Wilson Reservoir, Tennessee Valley Authority, USA, 1935-1940



Based on data from: *Malaria control on impounded waters*, Washington, DC, United States Public Health Service, Tennessee Valley Authority, 1947.

The flushing need not be automatic, but experience has favoured the self-initiating and self-terminating siphon structure as opposed to hand-operated gates. The successful design is based on inflow into storage during the time of peak vector propagation. Flushing ensures the deliberate imbalance of the otherwise near-constant stream conditions.

3.2.2 *Vegetation control*

The biology of many vector species is frequently associated with specific plants, whose control can be used to reduce vector populations. Approaches to such control can be conveniently classified according to whether the vegetation is aquatic or terrestrial.

In the case of many aquatic plants, control by methods of water management, already discussed, offers the major opportunity to create unfavourable environments for vector populations. These manipulations can be enhanced by suitably timed cutting programmes. Problems may arise, however, if the plant propagates by fragmentation.

Deep-water plants and mats of floating vegetation are not readily amenable to environmental manipulative measures. The most effective measure is to prevent their invasion of unaffected water bodies. Biological agents, such as herbivorous fish, may provide an alternative method. These are commonly used under certain conditions—for example, the grass carp is often bred in conjunction with rice cultivation and has the added advantage of providing a source of protein for human consumption.

With respect to terrestrial vegetation, there are two main manipulative measures: clearing, total or selective, to remove the vector habitat; and changing the existing vegetation. The first has been used on a large scale for tsetse fly control and on a much smaller scale for mosquito control. This approach is sometimes unacceptable where the plants concerned are of economic importance, and, in the case of large-scale clearing, other detrimental effects on the environment, especially accelerated erosion and sedimentation, may militate against its adoption.

The introduction, or reintroduction, of plant species has been used successfully to increase shade to discourage the breeding of some important anopheline mosquitos. In areas where the water-table is high, the planting of certain water-avid trees, such as eucalyptus, gives marked benefit in assisting drainage.

3.3 Reduction of man–vector–pathogen contact

Measures that can be used for reducing man–vector–pathogen contact include land-use restriction, personal protection, the vector-proofing of dwellings, and the provision of water supply and sanitation facilities.

3.3.1 *Land-use restriction*

Land-use restriction involves the identification and delimitation of the area within which man–vector–pathogen contact can take place and restricting access to such localities at times when contact is most likely to occur. This procedure can be used in the control of mosquitoborne diseases, onchocerciasis, trypanosomiasis and schistosomiasis. Its effectiveness in malaria control was recognized long before the nature of the disease was ascertained or its vector discovered. The restriction of land use may involve the relocation of settlements, the depopulation of areas declared as buffer zones, and the siting of new villages.

In the case of night-biting vectors land-use restriction may be relaxed during the daytime. For large engineering works such as man-made impoundments or desert reclamation projects, the right to depopulate the buffer zone must be obtained through outright purchase or through leaseholds. For diseases such as onchocerciasis, the need to relax land-use restriction after the disease has been controlled should be recognized.

The concept of "dry belting" of wet rice cultivation areas, where a buffer zone surrounding the village is restricted to dry crops such as pasture, is also based on land-use restriction. The width of the zone may be diminished if the vector species can be deviated from human to animal bloodmeals. This phenomenon undoubtedly occurs under natural conditions and can be deliberately intensified by the large-scale introduction of livestock into the buffer strip.

3.3.2 *House and individual protection*

Land-use restriction is not possible in some circumstances—for example, in many countries of south-eastern Asia, in which there is intensive pressure for the use of all agricultural land, and settlements must of necessity be located in areas where man–vector–pathogen contact takes place. Houses must be made vector-proof, which is particularly important in the case of vectors that feed during the

night. Examples of such measures are the use of mosquito screens and nets, the plastering over and filling in of cracks and holes against the ingress of rodents and triatomid bugs, and the provision of footbridges over streams, canals, etc. to avoid infection with cercariae.

3.3.3 *Water supply and sanitation facilities*

The provision of a safe and convenient water supply and facilities for laundry, bathing, and excreta disposal are recognized as essential in the control of vectorborne diseases. In the case of schistosomiasis these measures are aimed at minimizing contact with snail-infested waters, thereby reducing the infection of snails with miracidia and the infection of man with cercariae. The effectiveness of water supply and sanitation facilities depends primarily on their proper design, use and maintenance. The principal constraint in making them available is their cost. Efforts now under way to develop acceptable technologies at a reasonable cost need to be further strengthened and continued. These are basic sanitary measures that must be provided in all human settlements because they are effective for the control not only of vectorborne diseases but also of many other communicable diseases, and, in addition, play an important role in improving general wellbeing.

3.4 Integrated application of methods

After reviewing each of the main methods of environmental management for vector control, the Expert Committee examined the advantages that these methods offer. First, a single method may be effective against several disease vectors. As is shown in Table 2, vegetation control, for example, is primarily effective against tsetse flies and partially effective against *Anopheles*, *Culex* and *Aedes* mosquitos, and triatomid bugs.

Secondly, more than one method may be effective against one specific vector or disease. Again referring to Table 2, one will note that the blackfly vector of onchocerciasis is primarily affected by the impoundment of water and partially affected by water velocity and wave agitation, water level fluctuation, sluicing for flushing, the provision of water supply and sewerage facilities, and land-use restriction. Advantage should be taken of combining these methods to intensify the effectiveness of control operations.

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Table 2. Environmental management for vector control

Vector or intermediate host	Diseases transmitted	Environmental modification						Environmental manipulation						Modification or manipulation of human habitation or behaviour				
		Drainage (all types)	Total earth filling	Deepening and filling	Land grading	Velocity alteration	Impoundment	Clearing and burning of terrestrial vegetation	Shading or exposure to sunlight	Water level fluctuation	Sluicing for flushing	Aquatic vegetation control	Salinity regulation	Water supply and sewerage	Screening and bednets	Refuse collection and disposal	Land-use restriction	Improved housing
Anopheles mosquitos	Malaria	++	++	++	++	+	−	+	+	+	+	+	++	+	+	+	+	+
Aquatic snails	Schistosomiasis	+	+	++	+	+	−	−	−	+	+	+	+	++	−	−	+	−
Culex and *Aedes* mosquitos	Filariasis; viral and other diseases	++	+	+	+	+	−	+	+	+	+	+	+	+	+	+	+	+
Blackflies	Onchocerciasis	−	−	−	−	+	++[a]	−	−	−	+	−	−	+	−	−	+	−
Houseflies	Infantile diarrhoea	−	−	−	−	−	−	−	−	−	−	−	−	++	+	++	−	+
Tsetse flies	African trypanosomiasis	−	−	−	−	−	−	++	−	−	−	−	−	−	−	−	+	−
Triatomid bugs	Chagas' disease	−	−	−	−	−	−	+	−	−	−	−	−	−	+	−	−	++
Rat fleas	Plague	−	−	−	−	−	−	−	−	−	−	−	−	−	−	++	−	++
Cyclops	Dracontiasis	−	−	−	−	−	−	−	−	−	−	−	−	++	−	−	−	−

Key:

− = Little or no directly demonstrated value, or not applicable.
\+ = Partially effective (some species).
++ = Primarily effective (most species).

[a] Small dams = adverse effect; large dams = good effect.

Table 2 provides further, similar, examples of the application of environmental management methods and shows the relative efficacy of each method against each particular vector and the diseases it transmits.

3.5 Equipment for environmental management

The concept of using environmental management methods for the control of water-associated vectorborne diseases is well accepted; however, the reintroduction of the application of such methods has been slow. The environmental management activities being undertaken by vector control programmes are in general on a small scale, utilizing manual labour, and thus have not produced obvious and significant results. While labour-intensive methods should continue to be employed in most developing countries, in which an ample labour force is still available, it is nevertheless timely to consider introducing, wherever justified, suitable equipment as a way of improving and extending the application of environmental management measures in the control programme strategy.

In irrigation schemes, the authorities concerned are responsible for the maintenance of the irrigation and drainage systems, including canal cleaning and weed removal, and should have at their disposal the necessary equipment for these operations. The vector control services should cooperate closely with the irrigation authorities to ensure that the measures undertaken also provide an effective means of vector control.

In areas where no organized irrigation exists, the vector control services may be obliged to purchase part or all of the equipment required. The need for equipment is particularly indicated in situations where swampy lowlands exist and where vector breeding sites can be greatly reduced through the construction of simple drainage systems, filling and grading, etc.

The equipment chosen should be versatile (i.e., capable of performing various jobs), easy to operate, easy to maintain, and reasonable in both initial and operating costs. The rotary ditcher and the back-hoe seem to have such advantages. The types and makes already available in the country (in the local public works or agriculture departments) should be preferred, as this will provide an opportunity for mutual support in the operation, maintenance and repair of the machines.

Prior to introducing machinery on a large scale, it is advisable first to carry out a field trial to study the applicability (and limitations), output rates, operating, maintenance and repair costs, and other related aspects of each type of equipment whose purchase is envisaged. Such a trial will also provide an opportunity for the training of operators and maintenance personnel. Where possible, machines in the possession of other departments (public works, irrigation, for example) should be borrowed for trial purposes. These departments should be consulted before any type of equipment is selected. Proper maintenance and supporting services and appropriate scheduling of work are necessary, and operators should be given adequate training and be properly supervised.

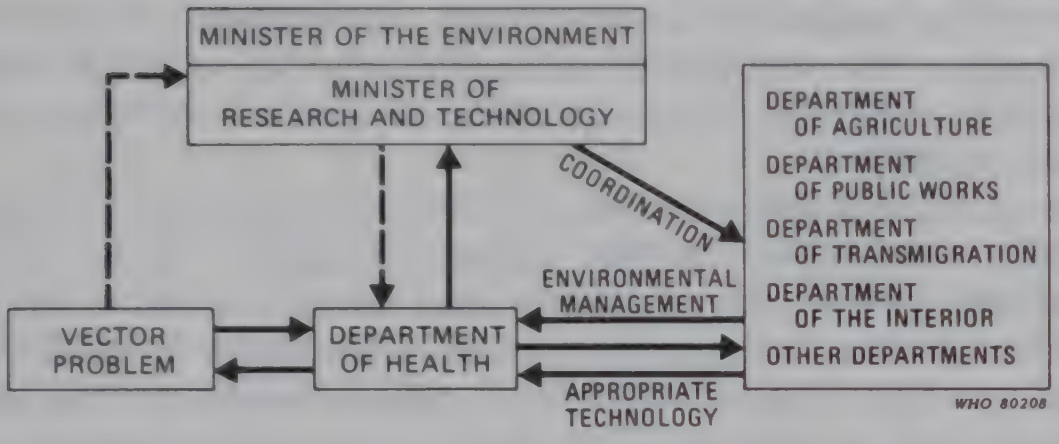
4. INTERRELATIONSHIPS WITH AGRICULTURE, IRRIGATION AND OTHER SECTORS OF SOCIOECONOMIC DEVELOPMENT

In agriculture and associated activities the application of environmental management measures is aimed, primarily, at the achievement of production objectives. Relatively few case studies exist of actual experience in the application of these measures for the control of vectorborne diseases. There is, however, evidence that both crop production and general health have improved as a result of environmental management. Studies of the impact of such measures, especially irrigation and drainage schemes, on health have led to a knowledge of the structural and operational factors affecting disease transmission. The problem usually encountered lies in the introduction and application of appropriate measures.

Since agricultural development—particularly when water use and management are involved—entails a change in the type or intensity of land use, it is in itself a form of environmental management, either through modification or through manipulation. Thus an opportunity is offered for collaborative efforts to plan and introduce simultaneously parallel or common measures for the prevention and control of diseases associated with the environment concerned. In the case of new development, this opportunity can seldom be perceived unilaterally by the responsible agencies. It is therefore at the planning stage that there is a need to bring together executing and supporting services, through the enactment of appropriate legislation, in a

combined operation, with joint participation and funding, to incorporate the necessary community health protection measures. By way of illustration, an example is given in Fig. 2 of a systematic scheme of cooperation applied to irrigation developments in Indonesia, indicating the pattern of intersectoral coordination.

Fig. 2. Structure for intersectoral coordination in irrigation development, Indonesia



A common problem, especially in irrigation projects, is the failure to plan, design and construct schemes that take account of the requirements of individual farms. This means that water control is only partial and subject to makeshift measures on the part of the farmer, who receives his supply in quantities and according to schedules which often do not suit his needs or match his management skills. Defects are therefore found in water management which affect crop production and have a strong bearing on the incidence of water-associated diseases. These defects are manifested in an excessive supply that leaves standing water in fields, inadequate drainage that does not permit the drying out of the land, the waterlogging of badly levelled fields, and unnecessary contact of the farmer or irrigator with the water.

The major incentive to adopt environmental management measures is generally economic. If the scheme can be shown to achieve better crop production and financial returns, there will be a positive response; on the other hand, increased cost without a better return will deter from the use of these measures.

A further incentive to the introduction of health measures in agriculture is increased convenience. This applies both to in-field activities and to community water supply and sanitation facilities. An

additional incentive will arise from the farmer's recognition of improvements in family health and the quality of life.

Existing schemes have already established their particular environment, in which the original conditions have been modified. As a result, many have created or intensified health problems. Moreover, many have failed in some measure to achieve planned levels of productivity and require structural and operational improvement to overcome this defect, particularly at the farm level. Such improvement offers a further opportunity for intervention in the interests of vector control, either through modification (structural and land shaping, for example) or through manipulation (water control by revised scheduling, better quantitative use, and different application methods).

An example of this is provided by the Blue Nile Health Project in the Sudan, the first of its kind to make extensive use of environmental management for vector control in combination with the operation of a major irrigation scheme.[4] The terrain covered by the Gezira–Managil irrigation scheme, which constitutes the major portion of the project area, produces 75% of the Sudan's main product—cotton, a crop that provides 60% of the country's foreign exchange earnings. After some 50 years of operation, it was decided to reassess the situation in the project area owing to the existence of problems of poor irrigation efficiency, low agricultural productivity and an unsatisfactory level of health. The project, which is the primary responsibility of the Ministry of Health in collaboration with other ministries, aims at the prevention and control of the major water-associated diseases—namely, malaria, schistosomiasis and diarrhoeal diseases—through a comprehensive approach, emphasizing environmental management for both vector control and agricultural improvement purposes.

One of the deficiencies in the effort to create an awareness of the potential effectiveness and value of introducing and maintaining health safeguard measures in agricultural schemes is the difficulty of proving and assessing their benefits. It is already difficult to convince farmers and the relevant authorities that greater productivity can be achieved through better land and water management, even though this can be measured in monetary terms and there are numerous

[4] Further information about this scheme is available, on request, from the Division of Vector Biology and Control, World Health Organization, 1211 Geneva 27, Switzerland.

examples to draw on. In the case of health improvement, the assessment of economic benefits deriving therefrom is less precise, and there are few convincing examples of outstanding success at the project level.

There is a real need to extend current knowledge through further research into the application of known principles in full-scale projects. Investigations must consist of scientifically sound and carefully controlled practical research programmes giving special attention to options for intervention and their associated costs at all levels, from the national implications down to the impact on individual farms. These studies should be carried out in conjunction with parallel work on water management for agricultural purposes. They should ensure full participation of the population directly concerned, which means the farmers and the rural community. Without their cooperation, the research programme will be incomplete and its results are unlikely to find willing acceptance.

Institutional support for the introduction and operation of health measures through environmental management should form part of the same structure as support for the development of land and water resources, as shown in the Indonesian example of intersectoral coordination (Fig. 2). This implies effective intervention at the national level, as well as at the district and scheme levels, involving such bodies as river basin authorities. Coordination should commence at the planning phase of any project which is aimed at or associated with the modification of existing environmental conditions and should continue throughout construction and operation. Support will be called for from bodies concerned with legislation, organization, training, extension, credit and cooperatives, since all these elements are essential to production processes, which will influence the future overall socioeconomic environment of the rural community. The success of this coordinated action will determine the ability of that community to sustain acceptable standards and improve the quality of life, of which health is a major component—albeit difficult to quantify in monetary terms.

In the establishment of programmes of vector control in agricultural development, the Expert Committee stressed the importance of identifying specific vectors, the types and locations of their habitats, their behaviour, and their importance in disease transmission. All these factors may vary from scheme to scheme and even within a single agricultural development. Without such identification there can be a considerable waste of time, of money, and indeed of

opportunity for effective action, even when the agencies concerned are fully cooperating. The Expert Committee discussed water management in rice-fields with special reference to malaria control through intermittent irrigation. It was agreed that this was a subject of major importance, particularly in Asia, and it was suggested that FAO and WHO should give it special attention under the terms of their procedures of collaboration in the prevention and control of waterborne and associated diseases in agricultural water development activities, as set forth in their joint Memorandum of Understanding.

The Expert Committee reviewed the relationship between blackfly control and agricultural development. In certain parts of Africa, the cultivation of scarce fertile lands has had to be abandoned because of the risk of blindness due to onchocerciasis. In such situations the control of *Simulium damnosum* would permit the repopulation of the abandoned valleys, which might then be put once more into productive agricultural use.

The Committee also discussed the problem of African trypanosomiasis and its relation to development in a *Glossina*-infested area of about 10 million km^2 spanning 36 countries south of the Sahara. The presence of trypanosomiasis greatly limits livestock production and integrated rural development, although much of the area contains some of the best pasturage in Africa, as well as good virgin land eminently suitable for agriculture. Vector control, where possible, offers the only practical and safe approach to eliminating the disease, including the large-scale use of insecticides accompanied by chemotherapy and the selective clearing of vegetation as a complementary tsetse fly control measure to create barriers to check fly breeding and reinvasion or to reduce fly–host contact.

An environmental change which often accompanies or forms part of agricultural development is that of a variation in the extent of tree cover through deforestation or afforestation—more often the former, which is also used as a vector control measure to remove actual or potential habitats, as in the case of the tsetse fly. However, such a change may also create an imbalance which is detrimental to the elimination or control of other vectors in or adjacent to the area of modification. Experience in Indonesia, where people were settled in the vicinity of mangrove swamps, provides a good illustration of this. The felling of the mangroves for firewood resulted in the elimination of shade from the lagoons, thus favouring the breeding of *Anopheles sundaicus*, which requires sunlight. Subsequently, mangroves were replanted for the production of material used in dye-making, and as a

result there is now a rejuvenation of forest; cropping is properly controlled; and the incidence of malaria has been reduced.

Deforestation also often increases erosion and consequently brings about a heavier sediment load in streams and rivers and in reservoirs and watercourses forming part of man-made schemes. The effects of impeded drainage, waterlogging and inundation all tend to raise the incidence of water-associated diseases, and there is thus a close link between the conservation and protection of land and water resources and the creation or reduction of possible health hazards responsive to environmental changes of this nature. A secondary influence may also arise from the depression of the local economy as a result of degraded land conditions, with a consequent reduction in the incentive or the financial ability of the community to introduce or maintain necessary measures either for production or for health protection.

5. IMPACT ON THE ENVIRONMENT

Impact is the term usually applied to the sum total of effects, both beneficial and detrimental, that an intended action exerts on a particular component of the environment. The overall impact derives from the integration and combination of all the different impacts that a whole project can produce on the total environment.

Regarding environmental management for vector control, the Expert Committee felt that careful study of the actual and potential effects that can be expected from an action (whether this is the erecting of a structure or the performance of an operation) and the comprehensive analysis of these effects, which will lead to the determination of immediate and delayed impact, form an essential component of the programme of pre-planning activities. The results obtained from such a study and analysis must be used by planners and designers of environmental management measures so that any possibility of degrading the quality of the environment can be foreseen and prevented or at least be reduced to a realistic minimum. The degree of reliability of the assumption that the project will not adversely interfere with the environment depends on the amount of attention given to and the thoroughness of the investigations, the assessment of impacts and the incorporation of resulting recommendations into plans, designs and programmes of environmental management for vector control.

The study of effects and the assessment of impacts, in order to be as comprehensive as required, demands the participation of a diversity of specialists in the many subjects related to the affected components of the environment. This work is possible only through effective coordination and collaboration of government departments, public institutions, private enterprises, etc., that can provide the staff and facilities required. The difficulty of obtaining such assistance and the time and expense involved in the task are factors that reduce the scope of these investigations. If resources are limited, an order of priority should be set so that the investigations cover at least the most directly affected elements of the environment.

In the study of the impact of environmental management measures for vector control it is important to:

(1) identify the ecological conditions of the area in which these measures are to be applied prior to the initiation of operations;

(2) define the constructions and activities proposed;

(3) envisage the short-term and long-term environmental changes that can be expected from the proposed structures and operations; and

(4) predict the imminent and long-term effects that these environmental changes may exert on the original ecological situation.

Once these effects and their probability of occurrence are foreseen, it will be possible to prepare plans, designs and programmes that would promote the effects which are beneficial and hinder those which are detrimental.

The Committee felt it to be essential that the results obtained from the impact study should be used in the planning and design of environmental management measures and that they should be embodied in the various operations to ensure protection of the environment.

Of all the methods of vector control, environmental management is the only one in which efficiency does not depend on the introduction of elements or agents extraneous to the natural environment. Environmental management consists mainly in the rearrangement, reshaping and reinforcement of materials already existing in the locale, and in the activation, adjustment and imitation of natural processes.

As mosquito vectors undergo an aquatic stage of development and snail intermediate hosts need water for their survival, it is logical

that measures of environmental modification and manipulation should be primarily aimed at eliminating or interfering with the physical, chemical and vegetative characteristics of water collections and courses that favour the multiplication of these host species.

The time, the site and the manner in which transmission takes place are factors to be reckoned with in the selection of methods and the planning of measures; consequently they will also indicate the geographical extent of impact studies and the elements of the environment which require particular attention in these studies.

A good example of the procedure for ensuring collaboration in impact studies is the mechanism established in the USA. The National Environmental Policy Act of 1969 rules that any federal agency intending to carry out a project that entails major environmental changes that would significantly affect the quality of the human environment must undertake at the early pre-planning phase an all-inclusive study of the possible impact on the environment that might result from the project. The executing agency is authorized to call upon other federal authorities and administrations at various levels of government—state, county, etc.—for assistance in this task and, if it is deemed necessary, to contract the services of universities, research institutes and other enterprises and individuals, so as to make use of the best knowledge and experience available for preparing the "Final Environmental Statement". This statement covers five main items:

(1) the predicted impact of the proposed action;

(2) the expected adverse effects that cannot be avoided;

(3) the study of proposed alternative actions and their relative merits;

(4) the analysis of short-term uses and the maintenance and enhancement of long-term productivity; and

(5) the identification of any irreversible and irrevocable commitments.

The whole procedure follows guidelines issued by the Council for Environmental Quality, on whose authority the project is ultimately accepted or rejected.

A similar procedure can be applied in projects utilizing environmental management for vector control, where the health authority as the executing agency or partner in the undertaking should have the authority to call upon other governmental agencies and institutions

for assistance in carrying out a comprehensive study of the possible impact on the environment that these activities may produce. Each contributor to the study should review and comment on the planning and design of the proposed environmental management measures, so that the overall environment is protected from unduly adverse effects. A matrix discussed by the Expert Committee for the evaluation of environmental impact could also be used as an *aide-mémoire* for the planning of impact studies and for inviting the collaboration of specialists (see Annex 1).

6. COST-BENEFIT AND COST-EFFECTIVENESS ANALYSIS

Decisions about which environmental management measures to use, and to what extent they should be used, should incorporate the results of the appropriate economic analysis.

6.1 Cost-benefit analysis

This is used to help planners to select from among the large number of development projects competing for limited resources those which are likely to make the greatest contribution to social and economic development. The analysis can be carried out at either (*a*) the intersectoral level, to choose among projects in many different sectors, such as agriculture, industry, transport, education and health, or (*b*) the intrasectoral level, to select among competing programmes within a single sector—e.g., malaria control, tuberculosis control, and maternal and child health care in the public health sector.

The basic purpose of cost-benefit analysis is to identify, quantify and value in monetary terms all benefits and costs occurring in each year throughout the life of the project. Once these are estimated the benefits and costs in future years are reduced to a common denominator.

Some terms used in cost-benefit analysis can be defined as follows:

Benefits:

(*a*) increased production and per capita consumption,

(*b*) improved balance of payments,

(*c*) improved distribution of income,

(*d*) reduced unemployment,

(*e*) improved health status,

Costs:

(*a*) financial costs—i.e., all money disbursed during the life of the project,

(*b*) opportunity costs—i.e., the value of benefits foregone by investing in the project concerned rather than in another project,

(*c*) social costs—i.e., nonmeasurable items such as degradation of the environment, personal inconvenience, and pain and other forms of suffering.

Present value of project cost: the total value of all costs incurred by the project in each year of its life discounted to their present value.

Present value of project benefit: the total value of all benefits generated by the project in each year of its life discounted to their present value.

Many workers have attempted to make cost-benefit analyses of health programmes. Unfortunately, none has produced complete and satisfactory results. The main difficulty lies in the identification and quantification of benefits which are actually attributable to the health improvement brought about by the project itself. Many developments take place simultaneously and thus the achievements are the outcome of collective efforts; the assignment of separate values to improved health or other developments is a difficult task.

Past attempts to quantify health benefits cover the following areas:

(*a*) the value of savings in cost of health care and services;

(*b*) the value of the increase in total output resulting from reduced mortality, disability and debility (investment benefits);

(*c*) the value of health improvement *per se* (consumption benefits).

An estimation of (*a*) is possible with a reasonable degree of accuracy. The current projected expenditures on health care or in respect of a specific disease can be estimated and thus the saving in these costs when the number of cases is reduced as a result of the application of the health programme can be measured. It must be remembered that the quality of the health care and services may change with time and it will be difficult to reflect this change in the

analysis. It should also be noted that people continue to demand health services as frequently after the project is implemented as before. The only result may be to change the composition of health expenditure rather than its total.

Disability and debility caused by diseases are more difficult to estimate. First, their duration varies (depending on the intensity of the disease) and it is not always possible to assign a standard period to each disease. Secondly, even given the same duration, the degree of disability and debility caused by a disease may vary in different individuals. Thirdly, quantification of disability and debility or even death in terms of economic losses (man-days lost) may not be very valid in many situations in which unemployment is rife and development markedly deficient.

On the basis of their field investigations, some workers have made estimates of economic losses due to a disease in an area or in a specific country, or have even indicated figures for increased production as a consequence of a disease having been brought under control. It should be emphasized that there are many uncertainties involved in such quantification.

The consumption benefits of health projects arising from the resulting reduction in human suffering are very difficult to measure. Nevertheless, the fact remains that good health is a condition of economic and social progress and in principle its value needs to be taken into account in cost-benefit analysis.

Owing to the difficulties of calculating valid cost-benefit ratios, as outlined above, public health programmes are usually at a disadvantage when in competition with projects sponsored by other sectors, whose benefits can be measured with greater accuracy.

Many environmental management methods of vector control also help to reduce the transmission of diseases other than the target disease, as well as to increase agricultural production through the improvement of irrigation systems. These accessory effects of specific environmental management methods need to be quantified and valued so that they can be integrated into the cost-benefit analysis of vector control projects.

6.2 Cost-effectiveness analysis

This is another resource allocation technique, which is usually considered an intermediate step in cost-benefit analysis. Whereas cost-benefit analysis seeks to determine whether or not a project

should be undertaken, cost-effectiveness analysis assumes that it should be and attempts only to select the least costly method of achieving the project's objectives.

Effectiveness is the quantitative measurement of the productivity of a technique, or piece of equipment, expressed in some appropriate unit of measurement. The cost-effectiveness of a control method is the ratio of effectiveness to cost over a specific period of time. This means that the greater the effectiveness or the lower the cost the more desirable will be the control method concerned.

The degree of effectiveness of environmental management techniques can be measured by utilizing the methods and procedures adopted for evaluating health programmes. For instance, the effectiveness of a residual spraying operation applied to combat malaria can be measured by reference to mosquito indices or to its impact on the transmission and incidence of the disease, or both. Likewise, the effectiveness of environmental management measures directed against mosquito vectors can be measured by the reduction in the number of larvae and by the eventual impact on disease transmission. To ensure that the results are comparable when the cost-effectiveness of a number of control methods is estimated, the same indicators and method of evaluation should be used in the measurement of degree of effectiveness.

The duration of effectiveness is an important factor, which should always be taken into consideration. Environmental management measures mostly produce long-term effects and thus, despite their initially high cost, may be more cost-effective than measures with short-lived effectiveness—e.g., pesticides application. There are also measures, such as the use of larvivorous fish, whose initial cost is low and whose effectiveness is usually long-lasting, though it may be considerably less so than that of most environmental management measures.

The correlation of period of effectiveness with cost-effectiveness should include all estimated or actual costs incurred during the specified period for which the analysis is made, including those of measures applied for maintaining adequate effectiveness of the control methods. As mentioned above, the cost-effectiveness analysis should also take into account the application of the method in controlling other diseases or in bringing about general health or social and economic improvement. Many environmental management measures whose primary aim is vector control are equally and sometimes even more effective in helping to increase agricultural

productivity and improve irrigation. Pesticides applied for malaria control may play an important role in reducing other diseases. For these reasons some difficulties are encountered in a comparison of the effectiveness of different techniques or of equipment with different characteristics.

Such is the case in schistosomiasis control when chemotherapy is compared with the provision of a safe water supply. The first method is curative, eliminating most of the worms from the human hosts, but does not prevent the possibility or reinfection at some later date. A safe water supply, on the other hand, is preventive and not curative, but it does reduce transmission, so that the incidence declines steadily year by year, along with that of some enteric diseases; thus the general health and social welfare of the population are improved. In this example one possible common denominator for the two control measures is the reduction of crude mortality rates. Since the death rate for schistosomiasis is generally much lower than the mortality attributable to waterborne enteric diseases, the provision of safe water supplies may be more cost-effective than chemotherapy.

To put the argument differently, one may compare the cost-effectiveness of providing a safe water supply between localities A and B. If A is in most respects equal to B but has schistosomiasis whereas B has not, then—using the same measurement unit as above—safe water supplies will produce a greater reduction in the crude mortality rate in locality A than in locality B and consequently should be considered more cost-effective.

Cost-effectiveness analysis can also be used as a tool to determine the optimum combination of control techniques under given constraints. Its use is therefore recommended in planning vector control programmes utilizing environmental management measures in combination with chemical and biological methods or chemotherapy.

7. PLANNING, ORGANIZATION AND EVALUATION OF ENVIRONMENTAL MANAGEMENT MEASURES

7.1 Planning principles

7.1.1 *Responsibility for planning*

Before any planning, organization and implementation is begun, some governmental agency must be made responsible and be

equipped with the necessary authority and means. The state has long provided the authority to supervise disease control, safety, morals, public order, the protection of property and the welfare of its citizens. Where problems of human disease are involved, the statutory authority for preventing waterborne and filthborne diseases has been created in one form or another in every country.

The ministry of health has the moral responsibility for the health of the citizens, whether or not the state has elected to give regulatory functions in this sector to departments of agriculture, labour, natural resources or other governmental agencies not otherwise concerned with health. At the local level every health department investigates complaints about vector problems as part of community sanitation programmes. The ability and skill of the health authorities to evaluate the nature and intensity of the risk to health and to assess the benefit of a proposed plan of intervention are vital for planning. The health ministry, in addition, usually includes a division of sanitary engineering (environmental health engineering). Thus, vector control management both for the control of disease and for the giving of technical advice and supervision to large-scale development projects known to have a vast potential effect on vector populations should logically be the responsibility of the ministry of health.

7.1.2 *Governing principles*

The whole planning process should take into consideration the objectives and scope of the project. It should be evident that a considerable advantage is gained when preventive environmental management measures are incorporated at the planning stages in large public works and disease-vector control programmes before vector problems develop.

Unfortunately, in actual practice, the opposite situation is more frequent: specific disease-vector problems already exist and environmental management must be applied to bring about control, whether large or small in magnitude. In the upgrading of an existing development, whether in urban sanitation, agriculture, deforestation, impoundment, irrigation, or population migration, the control of vectorborne diseases demands the greatest skills in planning. The desired goal must first be clearly defined, whether it is to prevent the introduction of a disease or to reduce an existing disease to a level at which the public health is no longer seriously affected. In this respect it may be useful to distinguish projects in urban areas of high

population density from those in rural areas with a sparse population, since the planning for vector control becomes more intense if a large number of people are to be protected. The possibility of future increases in the population is a factor to be considered.

7.1.3 *Comprehensive approach*

The Expert Committee noted that most special programmes are launched against a specific disease and certain control methods are used intensively. Other diseases relevant in the project area are usually ignored or other methods of control are neglected. The control measures directed against a specific vector by environmental management are usually effective against a whole range of vectors. A comprehensive approach involves well-balanced programmes aimed at the control of important disease vectors in an order of priority, utilizing a combination of available methods carefully selected on the basis of their efficacy, feasibility of application, cost, adaptation to local conditions, etc. This approach thus takes into consideration all the health factors as well as socioeconomic conditions and cultural patterns, and the plans of operations so developed will best meet the local conditions, needs and resources.

7.1.4 *Coordination*

Coordination is necessary at all levels both within the programme and with outside agencies. Other agencies will be involved whether the health authorities instigate the measures against the disease vector or whether they are asked to assist in specifying health safeguard procedures to be adopted in large-scale development projects. Most of these projects entail water resource and land management, so that irrigation, drainage, public works and communications authorities will be involved, together with the department of agriculture. Education departments may also be concerned, as will the local community. It is essential for the success of any project that coordinating committees representing all the interested parties and agencies should be established as early as possible. These committees have an indispensable role to play at all phases—from the initial planning to the final operation and maintenance stage. They will serve to define the aims, needs and interrelationships of all the interested parties, delineate functions, duties and responsibilities, assist in collaboration, avoid duplication and interference, resolve conflicts of interest and assist in the selection of procedures agreeable to all concerned.

7.1.5 *Legislation*

Many activities, such as the expansion of irrigation and impoundment, have given rise to serious health problems in whose prevention the public have had little or no say. The large number of municipalities, towns and villages involved has made the organization of defence slow, cumbersome and ineffective. The flight range of vectors knows no administrative boundaries, and a more realistic approach would be the consolidating of interested agencies through specific legislation in order to ensure their proper functioning and to protect the interests of all the parties involved.

Legislation should be regarded more as a guiding principle in the performance of a task than as an instrument of enforcement. It plays an important role in defining functions, assigning responsibilities and establishing procedures. In this way, conflict can be avoided between two or more agencies which, though they operate in the same area in pursuit of a common goal, have different interests and points of view. Legislation should be extended to govern the constitution of co-ordinating bodies so that the individual interests of all agencies concerned are duly taken into account, and correct decisions are made by streamlining and adapting these diverse interests.

A review of laws and regulations applicable to vector control in water resources development projects shows just how scanty and inadequate is this legislation in certain developing countries.

The need for proper legislation to stimulate and support programmes for the prevention and control of vectorborne diseases using environmental management measures is evident. Unless the health administration is invested with appropriate authority, it cannot carry out efficiently its duties and responsibilities.

7.1.6 *Information systems*

A well-organized information system is the basis of proper programme evaluation. (See section 7.4 for a full discussion of the rationale and techniques of evaluation in environmental management.) Great care is required at the initial planning stage to define what information is needed and how it is to be collected and recorded. Quality control should be maintained in order to ensure uniformity throughout the life of the project. Since all information systems have deficiencies, the accepted margin of tolerance should be decided at the outset. For environmental management, provision

should be made for the easy extraction of appropriate summaries to permit the monitoring of progress and the immediate identification of problems in all sectors.

7.1.7 *Training*

The interdisciplinary character of vector management will require a variety of basic science and engineering skills. These will be needed throughout the duration of the programmes or projects, from the initial planning to the maintenance and evaluation stage. There will be a particular need for at least a few highly skilled professional personnel in the planning process when data are assembled and design criteria developed. In addition, semi-professional workers and semi-skilled technicians will be required. The number of specialized personnel of all levels can be estimated when the magnitude and type of measures to be applied are known. In developing countries it will be necessary to organize the training of the requisite personnel—perhaps of every category.

If possible, such training should form part of inservice training, where skills can be transferred and reorientated to cope with the problem at hand. As far as the lesser skills are concerned, the training should be given by nationals of the country in question both in the field and in the laboratory and classroom. There are many alternative training approaches that have been applied in other areas of environmental management that may be used as a guide.

7.1.8 *Health education, community participation and primary health care*

Community participation is a beneficial and necessary element in programmes of environmental management for vector control that require the continuous support of the population. Communities do have mechanisms for deciding on and organizing tasks at their own level of operation. Experience has shown the advantage of learning from and building on these community structures to translate technical visions into realistic solutions as people themselves see them and are able to put them into practice. The people need to be fully informed as to what advantages and disadvantages the development schemes may bring and to be instructed about the interventions proposed to limit the adverse effects on health. In return, the community may be more willing to cooperate with the implementation, operation, maintenance and evaluation work.

Health education is important and useful in motivating community participation. Such participation, in the form of voluntary labour, may be essential in certain environmental management operations, such as filling in depressions, digging drainage ditches, maintaining stream banks, bush clearance, laying water pipes, or following correct agricultural practices. Whether this is done as a self-help project or for payment, the response of the local community will probably be better if the people understand the purpose of the work they are doing.

Primary health care tackles the main health problems in the community and provides and promotes a variety of services that are preventive, curative and rehabilitative. It is generally well understood in the community, since there is a considerable amount of direct contact with primary health workers. The opportunity is good for utilizing the influence of the health worker in stimulating individual and community cooperation with environmental management works for vector control.

7.1.9 *International Drinking-Water Supply and Sanitation Decade*

Commitment to the objectives of the International Drinking-Water Supply and Sanitation Decade (1981-1990) is widespread. The primary aim is to provide every individual by the end of the decade with adequate water supply and sanitation facilities.

It is felt that the International Drinking-Water Supply and Sanitation Decade could constitute a very important factor in the promotion and development of environmental management methods for vector control. To meet the decade objective many countries will probably have to triple or quadruple their efforts and outlays in connexion with water supply and sanitation, and in this regard it would be unfortunate if the opportunity were not taken of considering the health problems that might arise as a result of a possible increase in vector populations. On the other hand, adequately planned and designed wastewater disposal systems, in particular, would represent a very important tool for environmental management and vector control. Likewise, the provision of a safe and convenient water supply has proved to be very effective in reducing the incidence of schistosomiasis through the reduction of man–vector–pathogen contact.

In the planning and development of water supply and sanitation programmes during the decade, every consideration should be given

to the promotion of environmental management methods for vector control, at least in the case of major schemes and particularly in areas where vectors are a public health problem.

7.2 Planning procedures

The technical planning of environmental management works as an integral part of a vector control programme involves the following activities: (1) review of existing information on health and related subjects; (2) surveys to fill in any gaps in information; (3) identification of current and potential health problems; (4) determination of the relative importance of the health problems to establish priorities for prevention and control; (5) formulation of the control strategy in order to achieve the desired degree of control; and (6) preparation of a detailed plan of operation. In the case of water resources development projects, the major steps to be taken in the prevention and control of vectorborne diseases during the planning and subsequent phases are presented in the form of a checklist in Annex 2.

Thus, the first step in the planning exercise is a careful appraisal of the existing problems by assembling epidemiological, biological, entomological, and engineering data pertaining to the diseases and vectors of interest in the area concerned. Included in this collection of information are the details of any past surveys, mortality and morbidity statistics, and hospital and clinic records, as well as maps of the whole project area. Highly desirable are maps drawn to a scale of about 1:60 000 showing railroads, cities, towns, villages, streams, ponds, lakes, marshes, etc. If such maps are not available, vector control planning will be difficult and may require the drawing of sketch-maps in the field. A larger-scale map (about 1:10 000) is required to indicate the location of biological–entomological collection stations for calculating the densities of both immature and adult vectors.

It has been recognized in studies of many vectorborne diseases that seldom, if ever, are these diseases distributed uniformly over a large territory. An attempt should therefore be made to stratify endemicity and to locate the foci of transmission for diseases of major prevalence. For planning environmental management works, it would be important to locate and map out areas of considerable vector abundance and great vector-breeding potential.

It may be necessary to conduct field parasitological surveys to complement the available information and to identify the extent and

intensity of transmission. In such instances, depending on the disease, the location of houses must be indicated on maps, a census made and population movement monitored so that prevalence and incidence rates can be calculated through blood, stool or skin-snip examinations, as required.

The results of these parasitological surveys can then be suitably displayed on the map, together with data on vector bionomics. Providing the surveys were conducted when transmission was expected to be high for the area, the extent and severity of the problem can be delimited. Similar surveys extended over one year or more need to be carried out to define the season, area and intensity of transmission.

After the relevant information has been collected and analysed, it may be possible to identify the current and potential major diseases, to determine their relative importance and to establish priorities for their prevention and control.

Cost-effectiveness and feasibility studies on the various methods of control deemed to be effective should be carried out. Alternative control strategies can then be formulated and field tested with a view to selecting the most cost-effective and feasible for application under local conditions. Cost and the period and degree of effectiveness should be the important factors to be considered in the final selection of control measures. It is important to emphasize the concept of capital cost recovery in a comparison of recurrent versus permanent management methods. For capital cost, C, of measures, the annual cost, AC, will depend on the interest rate, r, the expected service life in years of the work, n, and the annual cost of operation and maintenance, OM. This can be expressed as:

$$AC = Cr + \frac{Cr}{(1 + r)^n - 1} + OM$$

Prevailing environmental and institutional factors also influence the applicability of control measures and should be given due consideration when a control strategy is formulated. It must be borne in mind that social and cultural factors may restrict the suitability of the measures proposed. One striking example is the provision of a water supply using a technology beyond the ken of the local population, who are consequently unable to operate the facility. Obviously, environmental management for vector control that employs sophisticated methods (large and complex undertakings involving the use of heavy,

foolproof machinery with high operating costs and necessitating a ready supply of spare parts and maintenance skills) must be compatible with the resources and situations for which the operations are intended.

These factors, as well as those mentioned in section 7.1, need to be investigated in respect of every method of environmental management selected as well as for other methods needed to construct the control strategy. Sometimes such factors are known through previous experience. If not, pilot field trials need to be organized to select the mix of methods which provides the best alternative strategies.

Details of the control and evaluation activities, their scheduling, the organization, manpower and equipment required for carrying them out, the estimated costs, the training programme, the needed legislative support, the proposed pattern of coordination with other agencies, the interrelationship with primary health care and the International Drinking-Water Supply and Sanitation Decade, community participation, the reporting systems, and any other relevant aspects of the vector control project should all be clearly defined in a plan of operation. For this, detailed engineering surveys and designs would be required to provide for all areas to be covered by environmental management operations.

The plan of operation, in addition to being a planning document, will serve as a basis for evaluation.

7.3 Implementation and organization of environmental management programmes

For a long time environmental management operations have been considered as basic vector control measures in disease prevention and control programmes. Ever since they were first used, in operations against mosquito vectors of malaria in the early twentieth century, they have proved their worth, as described below.

(1) *They are effective*, since once a body of water is drained, or filled and dried, or manipulated in any other way to discourage the propagation of disease vectors, the vector population declines and with it the prevalence of the diseases transmitted.

(2) *They have long-term effects*, since once implemented they remain effective for years, needing little or no maintenance. Any maintenance that is required is moderate in cost and simple in

operation and never begins to approach the scope, frequency and complexity of that needed for recurrent operations, such as, for example, chemical control.

(3) *Their overall costs are lower*, because environmental modification works are often operations that are performed once and do not have to be repeated, possibly requiring a higher initial capital expenditure but having an effectiveness that extends over many years. The water and land management works and structures dating back many years in numerous countries (India, Malaysia, the Philippines, etc.) are still in operation, and some of them have required no major maintenance.

(4) *Simple modification operations entail expenditure within the budgetary limits of most vector control programmes* and can be carried out successfully with only a small proportion of the budget—e.g., 10%—allocated annually for this purpose. Over the years the long-term effects allow for the transfer of resources to new areas and thus lead to the extension of control operations.

(5) *Their side-benefits are considerable.* Additional water and land may become available in rural areas for agricultural extension and in urban areas for housing and recreational activities. Most environmental management works contribute to increased crop yields and better quality agricultural produce, land preservation, etc.

(6) *The environmental impact is considerably less harmful*, since these operations are limited to environmental alteration, either of a temporary or sometimes of a permanent nature, which is in no way harmful to the quality of the environment. No environmental contamination will result—which might not be the case with other methods of vector control.

(7) *No special safety measures are required*, and the residents of the area, as well as the labour force involved, do not have to be protected against toxic hazards.

7.3.1 *Scope of application*

Environmental management operations have a prominent place in almost any vector control programme. They have a wide range of application in vector control operations in arid and semi-arid areas, where the scarcity of water for irrigation and other uses restricts vector breeding and increases the economic viability of the operations, a factor which weighs heavily in the selection of this method of control.

In tropical zones environmental management measures are specially indicated in urban areas, where their application is both administratively and financially feasible and would lead to an improvement in general sanitation.

Environmental management measures are essential in areas where malaria eradication programmes have reached the maintenance phase and where receptivity is high owing to an abundance of vectors. In areas cleared of malaria, usually at high cost, these basic operations have to be planned and carried out to lower the vector-breeding potential and to avert the risk of a resurgence of the disease.

Above all, environmental management measures for vector and disease prevention and control are indicated in development projects, especially those dealing with water resources. Integration of operations can be effected at the commencement of these projects in the surveys, planning, design, and construction stage and continued during their operation and maintenance. Possession of both adequate finances and the requisite professional and skilled manpower greatly facilitates an integrated approach and ensures the building up of an appropriate mechanism in the project administration to deal with the prevention and control of vectors and the diseases they transmit.

7.3.2 *Integration with other methods of vector control*

In a vector control programme, the integration of environmental management measures with other methods of control is greatly dependent on the need for these activities and whether this is a long-term or short-term need. It also depends on the applicability of the methods under local operational, financial and administrative conditions, and finally—and perhaps most important—on their cost-effectiveness ratio (including long-term and side benefits) and risk-benefit analysis as compared with those of other methods of control. These factors should be assessed during pilot operations prior to detailed planning and taken into consideration when control methods are selected and control strategies are developed. The control strategy should be elaborated using all feasible control methods in relation to time, extent and intensity, as dictated by programme requirements and on the basis of the factors discussed above.

Normally, low-cost simple environmental management operations should be carried out in the initial stages. To achieve a quick

impact, these operations should be concentrated in one area or in a number of limited, well-defined areas in various parts of the country. This will make it possible, within a few years, to reduce the application of chemical methods in that area and to move on to another area, using the savings deriving from the reduction in chemical control for the further expansion of environmental management activities. As work progresses and experience and expertise accumulate, power equipment should be introduced to increase work capacity in the interests of rapid expansion.

The organization of work for application of the integrated control strategy should be planned taking into consideration the extent and intensity of each activity in different areas each year. If the programme is a long-term one and has limited resources and thus is making a modest start, vector control operations should consist of a combination of simple environmental management and biological control measures, perhaps accompanied by localized chemical treatment in areas of high endemicity. In organized disease control programmes the intensive application of chemical methods with chemotherapy, combined with the gradual development and extension of environmental management and biological control, would normally form the initial control strategy. As already mentioned, the use of costly chemicals will diminish with growing experience and expertise, and as the effects of environmental management measures become increasingly apparent, it will be possible to divert resources to the extension of environmental management measures to other areas.

The training of staff and continuous assessment of the work should constitute permanent features of any vector control programme to allow for gradual progress from an intermediate strategy to a basic approach to vector control in disease control programmes. As the scope of environmental management works goes beyond vector control and covers other health sectors, as well as agriculture, public works, etc., the importance of coordination with other agencies and community participation is evident, as discussed above.

7.3.3 *Organization and implementation*

Environmental management measures for vector control can be introduced in (1) operating programmes, (2) new programmes, and (3) development projects.

(1) *Operating programmes*

In these programmes an organization, staff and budget already exist and thus they only need to be gradually reoriented to allow for the introduction and extended application of environmental management measures. At present, these measures are applied on a very limited scale in some programmes, and therefore the experience, technical expertise and facilities available are also very limited. The process of introduction and expansion should thus be gradual and take place in stages in order to prevent any undue delays or upheaval in the normal running of the programme.

The most practical approach would be to begin with the training of staff and the organization of field operation trials to assess the operational feasibility, cost-effectiveness and other implications of applying these measures as part of the programme. At a later stage, the organization of the programme must be revised and reoriented towards an integrated use of environmental management measures.

(*a*) *Preparation and training of staff.* A knowledge of field conditions and local possibilities as well as of environmental management methods is essential for the rational planning of an integrated approach and for its implementation in the field. Staff need to be conversant with various methods and with the equipment required to apply them so that they will be able to plan operations in consonance with each set of field conditions. As experience accumulates, the staff may be trained in more complicated operations using more sophisticated techniques and equipment. For this, some programmes may require highly qualified staff with a background in sanitary engineering and environmental management.

(*b*) *Pilot operations.* These operations are aimed at investigating the feasibility and implications (including the environmental impact) of various environmental management methods and their cost-effectiveness and cost-benefit relationship under different conditions. They are also aimed at developing appropriate operational procedures and practices for an integrated field application of all methods. It may be necessary to organize several pilot operations in different programmes, priority being given to programmes and areas where the operations are most needed or have a greater prospect of success. Areas with vector-resistance problems, development projects, urban situations, and arid or semi-arid endemic areas are among those to which high priority should be given. Qualified engineering

staff as well as epidemiologists and entomologists should be permanently assigned to pilot operations, and consultant environmentalists, sociologists, and perhaps economists should also be available. The operations should be extensive enough to cover a wide variety of field conditions and to allow conclusive assessment of results. A duration of at least three years is considered necessary, but some preliminary results may be available for application to programmes after the second and even possibly after the first year. Pilot operations can also be used for the practical training of staff.

(*c*) *Reorientation.* When staff training and pilot operations are well under way, studies should begin on methods of reorienting the services. This reorientation should allow for the absorption of the trained staff, who will carry out the planned activities. Programme reorientation involves a reorganization of the service in relation to new objectives and activities. It requires a gradual change of emphasis towards longer-term studies and programming and calls for the closer coordination of activities and collaboration with other health sectors and with agriculture, irrigation, public works services, and other development projects. Similarly, reorientation should be introduced in provincial and field services and units. There is a need for a gradual transfer of decision-making and planning authority to provincial units, which require this authority to study, plan, organize and coordinate activities within the general plan for vector and disease control and to assess the results. An important feature of reorientation should be provision for continuous progress towards an integrated control programme with a comprehensive approach that not only pursues the primary objective of controlling diseases, but also makes every effort to obtain the maximum benefit from the programme in other, related, fields, such as general health and agriculture.

(2) *New programmes*

In new programmes environmental management should be taken into consideration at the outset and included in the planning of various activities as an integral part of the control strategy. During the surveys and feasibility studies attention should be given to the collection of data and documentation that would permit the identification of areas where environmental management operations could be envisaged. During the planning phase detailed information should be collected on topography, hydrology and geology, etc., in addition to that on the epidemiology of the disease and ecology of the vector

to allow the planning of environmental management measures in the control strategy and their evaluation as the programme progresses.

Normally, vector control programmes aim at an initial sharp reduction—during the first few years of operation—in disease prevalence and transmission, followed by a long period of consolidation of the gains, while the disease continues to be steadily suppressed until it reaches a desired or possible control level. Quick-acting methods of control—e.g., the application of chemicals—together with the treatment of cases of human infection, are the major methods usually resorted to. During this initial phase the opportunity should be used to complete the reorientation and training of staff, initiate and expand environmental management activities and proceed with the required reorganization. As the programme approaches the consolidation stage and as environmental management activities develop and expand, the stress on the chemical control of vectors can be relaxed to a point where these measures are applied only in areas where environmental management works are too costly or very complex. Stocks of chemicals should be held to meet emergencies and epidemics.

(3) *Development projects*

In these projects the pattern of planning and the implementation of environmental management should be much the same as in new programmes. The only exceptions are the greater availability of financial and manpower resources and, to a large extent, the expertise required for the planning and implementation of environmental management works. In these instances the association of health specialists in the planning, design, construction, operation and maintenance phases of the project is essential. The extent of their participation, however, depends on the degree of seriousness of the problem created by vectors, to what extent they interfere with normal socioeconomic development, and the degree of control that will be desired. Taking into consideration the importance of the population's good health and wellbeing as one of the objectives of the project, the organization of an appropriate health component might, in most cases, be necessary.

7.4 Evaluation

Evaluation may be defined as the systematic and scientific process of determining the extent to which any action or sets o

actions have been successful in the achievement of predetermined objectives. It involves the orderly collection, analysis and interpretation of information on the subject with a view to identifying alternative courses of current or future actions. The process of making a selection from among these alternatives constitutes decision-making, which has come to be regarded as one of the three cardinal processes of modern management, the other two being evaluation and communication. Since decision-making serves as the basis of control in management, it follows that evaluation, the basis of decision-making, is of fundamental importance. In fact effective evaluation is indispensable if the success of projects and of management in general is not to be left to chance. Many countries and institutions are rapidly recognizing it as a powerful tool not only for improving the quality of programme planning and execution, but also for ensuring progress, for avoiding the waste of scarce resources, and for deploying such resources to the greatest advantage.

Evaluation involves the following three activities:

(1) collection of information about actions or about the subject of interest;

(2) comparison of this information with specified norms and criteria or predetermined objectives; and

(3) formulation of conclusions from the above comparison, and the identification of alternative courses of action.

The collection of information used for .the comparison, and the nature of the norms and criteria used in the comparison are considered crucial.

Evaluation should be a built-in mechanism of any programme. This could be considered as the internal evaluation of the programme and is meant to pinpoint the areas where remedial action is required and determine the time when it should be applied. In large-scale programmes, however, this internal evaluation should be supplemented by independent evaluation, to be carried out by personnel not connected with the programme and, in some instances, from outside the country. Whereas internal evaluation is a continuous process, external evaluation may be conducted periodically—for example, prior to decision-making regarding the future reorientation of the programme, or after its completion to assess the achievements.

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7.4.1 *Operational evaluation*

Operational evaluation is a continuous process directed towards current actions and operations in progress. It is primarily concerned with a programme's direct outputs as well as its direct and indirect costs, and is undertaken during the implementation phase. It involves studies on the progress and quality of work and on the soundness of technical, administrative and financial operations. The purpose of operational evaluation is to identify significant deviations from plans and norms and to correct these anomalies. Its sphere of action includes ascertaining whether work is progressing according to schedule, whether the methodology employed is proving effective and whether the workers' performance is meeting qualitative and quantitative norms. It helps to determine and to control costs, to assess accountability, to improve performance and also to increase interest in jobs and develop critical attitudes in staff.

Operational evaluation should consist of the following consecutive steps:

(1) planning of the evaluation process;

(2) implementation of the planned evaluation process;

(3) continuous assessment of the evaluation process with regard to its implementation and impact; and

(4) application of the results of the evaluation for modifying and replanning the programme and the evaluation process, as required.

The value to be derived from the evaluation will depend on:

(1) the nature of the information used in the evaluation as well as the manner of its collection and analysis; and

(2) the appropriateness of the specified norms and criteria.

For large-scale projects it is reasonable to expect that the basic source of information for operational evaluation will be the detailed plan of action drawn up for project execution on the basis of general guidelines in the planning document. The use of network analysis in work scheduling and resource allocation facilitates the evaluation. Such networks may be event-oriented as in PERT (project evaluation and review technique), or they may be action-oriented as in CPM (critical path method). According to Martino,[5] event-oriented

[5] Martino, R. L. *Project management*, Wayne, PA, Management Development Institute, Inc., 1968.

network formulations are likely to lead to scheduling errors. In any case, since evaluations are concerned with the assessment of actions, it would appear that action-oriented networks might be more applicable.

Norms and criteria used in operational evaluation can also be found in planning documents. They may be buttressed by general managerial and financial regulations used by the executing agency.

Planning for operational evaluation would involve the establishment of the intervals at which the evaluation information would be collected and the selection of those who would compile it. Methods of information storage, retrieval and processing may vary widely. For large-scale projects computer storage and processing may be necessary; for small-scale projects involving community participation simple record cards or notebooks may suffice.

Documented work plans are always available for large-scale projects, but they may not be available for small-scale projects. However, in view of their value for project execution and evaluation, every effort needs to be made to prepare them for all projects worth undertaking, regardless of their scale.

7.4.2 *Epidemiological evaluation*

Epidemiological evaluation of the impact of intervention measures on any disease is made on the basis of a few measurable indicators. According to each situation, the values of these indicators are compared:

(1) to fixed targets;

(2) to situations prior to the application of measures; and

(3) to the epidemiological features prevailing in comparable areas where no measures have been applied.

Furthermore, the correlation of epidemiological findings with the quality assessment of operations is an essential element for the proper conduct and success of a programme, without which a correct interpretation of the results cannot be made. It is for this very reason that the qualitative evaluation of the operations based on criteria of performance is considered to be an integral and essential component of operational evaluation.

To evaluate the effect of the chosen environmental management measure against a given vector, adequate baseline or precontrol data must have been collected. Changes may be looked for at various levels. The crudest will be those in the gross, overall vector population in the control area. However, in many cases only a fraction of the total vector population is involved in transmission and it is the changes in this fraction which require monitoring. Even more informative will be the monitoring of changes in the prevalence of the parasite in this fraction. In cases in which the parasite has a free-living stage within a specific habitat, changes in the levels which are present will provide additional information.

Ideally, it should be possible to set up a schedule of predetermined target levels for the densities of vectors, or for their infection rates, or for both, which should be achieved at any specified time after control measures have been implemented. Previous experience in pilot or even large-scale control programmes can assist in predicting these target levels; predictive mathematical models may also be of assistance. In many cases, though, such information is not available and constant surveillance and monitoring, after control has begun, will be necessary to decide if the control measures are working. If little or no effect appears to be taking place and operational evaluation is positive, then the whole strategy and tactics may have to be reviewed and revised.

Obviously, it may be claimed that transmission will be interrupted when the vector has been totally eradicated. Experience has demonstrated, however, that eradication of the vector by whatever means is seldom if ever achieved. It is conceivable to assume that transmission might cease when the vector intermediate host densities have been reduced below a threshold or critical level, which varies considerably with the vector and for the same vector in different areas with different epidemiological conditions. For most vectorborne diseases it is not possible to predict with any certainty what this level is.

It therefore follows that for environmental management methods the ultimate measure of success is to demonstrate that transmission of the pathogen to man has been successfully interrupted or diminished to a predetermined level. The appropriate measurements will vary according to the species, type and strain of the pathogen. Measurement of the effect of control measures requires reliable and adequate precontrol data and possibly a comparison area where the vector and the disease are simultaneously monitored in an undisturbed environment.

In the epidemiological evaluation of schistosomiasis control, the following two points deserve special attention:

(1) In contrast to protozoa and viruses, which cause infection through the multiplication of a few of these organisms within man, most helminthic parasites do not multiply in man. Thus, in schistosomiasis, a realistic goal for environmental management would be to reduce transmission. This will ultimately reduce prevalence and minimize the number of heavy infections with which severe disease is usually associated.

(2) Throughout the various phases of an environmental management operation, it may be necessary to change or alter techniques used to evaluate vector–disease indices. In such cases, care should be taken to ensure that the results obtained from different techniques are comparable. For example, with *Schistosoma mansoni*, the prevalence and intensity of human infections can be estimated adequately in the precontrol phase with the relatively insensitive Kato direct smear technique. If control is eventually successful, then a much more sensitive diagnostic technique may be required to detect infections.

A simple mathematical/epidemiological model which can be used for the evaluation of environmental management measures employed in malaria control is given as an example.

The dynamics of malaria in a population is related to the force of infection, h, or risk of infection, which is a function of a number of factors, namely:

(i) the density, m, of the vector(s) in relation to man;

(ii) the daily survival rate of the vector(s), p;

(iii) the average feeding frequency of the vector on man, a;

(iv) the level of parasitaemia, x (and of gametocytaemia, g, which is a fraction of x);

(v) the proportion of infective to infected mosquitos, b, and;

(vi) the duration in days of the sporogonic cycle, n, which is the time-lag between the ingestion of gametocytes, male and female, by the *Anopheles* mosquito and the appearance of sporozoites in its salivary glands. The duration of the cycle is a function of temperature and of parasite species and strains, and is in general between 8 and 14 days.

Taking into account the mathematical expression of the sporozoite rate,[6] this force of infection, h, could be expressed by the equation:

$$h = \frac{ma^2bp^ngx}{agx - \log_e p}$$

It could also be calculated by establishing the parasitological inoculation rate of the disease in cohorts of nonimmune populations.

The environmental management measures used in malaria control act either (*a*) on man–vector contact by reducing the man-biting rate, or (*b*) on the anopheline population, directly on its larval stage and indirectly on its adult stage, by reducing its density.

If one considers the above equation, it is possible to infer that any change in one of its factors will produce predictable and calculable changes in the force of infection. Whatever measures are finally selected, it is necessary to define to what degree it is necessary to reduce the value of the force of infection, h. By simple calculation, it is easy to estimate what should be the higher permissible values of m, a, and ma, in order to attain a value of h compatible with the objectives pursued. Therefore, the maximum permissible values of m, a, and ma could be used as indicators once it has been ascertained by field trials what impact well-applied environmental methods are producing.

Similar approaches could be applied for the study of other diseases under the impact of control measures.

7.4.3 *Environmental impact assessment*

During the application of environmental management measures, it will also be necessary to assess their effect on the environment as a whole. Techniques for assessing this environmental impact are still in their infancy and, because of the wide variety of situations in which such assessments will have to be made, hard and fast rules cannot be laid down. The situation is complicated by the fact that many of the factors which are likely to require consideration are not readily amenable to quantitative measurement. However, a technique has been developed to assess subjectively the effects on the environment

[6] See: Macdonald, G. *The epidemiology and control of malaria*. London, Oxford University Press, 1957, appendix 1, p. xvi.

of environmental management measures. A matrix that can be used for presenting the results of an impact study in tabular form is shown in Annex 1.

7.4.4 *Economic impact assessment*

When properly designed and correctly carried out environmental management methods of vector control produce important benefits to agriculture, irrigation, urbanization, environmental quality and the total socioeconomic system. An assessment of such impacts not only is essential for monitoring and measuring the success and implementation of corrective actions but is also required to demonstrate the dimensions of beneficial impacts, to attract interest and to ensure increased funding for the extension of these measures.

Economic impact studies require advance planning and the collection of reliable indicators against which progress and achievement can be checked and quantified. These indicators may be improved agricultural production, increased land and water for cultivation, better housing, greater income, etc. For such studies the services of qualified economists and social workers would be required.

8. TRAINING AND INFORMATION SYSTEMS

8.1 Training

Training is a vital activity in environmental management for vector control. The objective of training is to make prospective or existing staff fully effective in their jobs. When properly designed, timed and implemented, training programmes help to make good the deficiencies in newly recruited employees; they help existing staff to discharge their duties satisfactorily; they help to prepare staff for promotion and to assume new responsibilities; and they further the solution of problems identified by management itself or brought to light by operational evaluation. In environmental management, training should seek not only to develop technical skills but also to ensure that staff acquire positive attitudes towards the work.

Manpower requirements for an organization responsible for environmental management for vector control include planners, project managers, evaluators, operators, laboratory and field

technicians, and supporting technical staff. Training is required for all categories of workers. Such training may take place in training establishments external to the organization or it may be provided as an internal facility. In either case the choice of training programme should be based on the specific, current and projected needs of the organization. Where the training takes place externally, it may sometimes be necessary for the organization to search for suitable candidates to take part in ongoing training programmes. But, in general, it is preferable to seek training programmes that suit the needs of prospective or existing staff.

Where the training programme is internally organized and run, it is best treated as a cyclical process involving planning, implementation, evaluation and replanning. The planning stage normally involves an assessment of training needs on the basis of job requirements and the deficiencies of prospective students, which may be revealed through interviews or through performance appraisal. The results of the assessment would lead to the setting of objectives in terms of the capabilities that the students should have acquired at the end of the training programme. On the basis of these objectives, the detailed training programme can be designed, with subsequent evaluation and improvement.

Training programmes are needed for the three major categories of staff: the unskilled and semi-skilled workers, the semi-professional workers, and the professional workers.

The major requirement for unskilled and semi-skilled personnel is the development of appropriate psychomotor skills. Training can best take place on the job, in field situations, with the support of audio-visual aids.

Semi-professional staff, especially those involved in activities connected with preoperational and postoperational evaluation, need appropriate field and laboratory training. In addition to internal training, it may be necessary to provide opportunities for certain personnel in this category to acquire training outside the organization at national, regional or international training centres. The training of such personnel should be broadly based to provide for flexibility and to facilitate adaptation to new jobs.

Professional personnel who may be involved in environmental management for vector control include biologists, chemists, ecologists, economists, engineers, entomologists, epidemiologists, health educators, parasitologists, planners and managers, public health administrators, sociologists, and statisticians. Special internal

training programmes may be designed for such personnel, using educational consultants. Further training can be provided through demonstrations, special lectures and seminars, conferences, workshops and postgraduate university courses.

There is a worldwide shortage of professional workers in environmental management. To recruit and retain trained staff adequate incentives should be provided, including, in particular, financial recompense for working under conditions which are often arduous and unattractive. International and bilateral assistance may be required in organizing training programmes at local, regional and international levels. Such assistance may consist in the provision of instructors, equipment, educational aids, fellowships, travel grants and guidelines on training which can be used for preparing local training programmes. As an aid to the development of training programmes it is recommended that a training manual should be prepared at the international level for use in environmental management programmes for vector control.

Training should not be limited to those involved directly in the control programme. Appropriate training programmes should be designed for all civil engineering students, for all professional personnel whose work impinges on the environment or affects vectorborne diseases in one way or another, for policy- and decision-makers, and for communities. The object of each of these training programmes should be to enable the trainees to appreciate what they can do to prevent vectorborne diseases and promote public health. Such training is particularly important for irrigation engineers, water resources engineers, agricultural workers and development planners, and can be made available through the organization of workshops, the preparation of manuals and the circulation of technical reports.

8.2 Information systems

A wide variety of information is encountered in the course of environmental management for vector control. Some is vital to the success of the programme. Effective communication, a cardinal activity in the control programme, depends on the flow of information for planning, management of the implementation phase of the programme, and the evaluation of operations and impacts. The key elements in the effective organization, storage and retrieval of such information are forms, records, and—above all—the staff

responsible for the collection and processing of the data. It is on the competence, and therefore the training, of such staff that the reliability and value of all information depend.

8.2.1 *Forms*

Forms are the starting-points of record-keeping for programmes. They are designed to record information in such a way that it can be easily located, manipulated and compared with norms and criteria. A well-designed form should achieve its purpose with the minimum use of space, effort and time. Forms should be reviewed regularly to ensure that they are current and relevant. This requires periodic assessment of all forms being used on a job, a review of the information they contain, a simplification and consolidation of the information on essential forms and the discarding of forms no longer needed.

8.2.2 *Records*

Records are to management systems what memory is to man. They are, in effect, documented memory. Recorded actions may be written, or documented by a variety of devices—photographic, xerographic, mechanical or electronic. Programme actions need to be recorded to maintain continuity and to facilitate the evaluation, control and replanning of programmes. Records should be properly managed to provide quick access to information in active use, to put into efficient and low-cost storage documents required for possible future use, and to discard those no longer of use.

8.2.3 *Reports*

Reports are communications which provide feedback on the past and current operation of a programme. Their value depends on how well they inform decision-makers about programme performance and how well decision-makers, in turn, make use of the information they convey.

Reports are vital for evaluation. Hence, as far as possible, they should present information in relation to the objectives and norms of programmes. They should indicate how well programme actions have been carried out and at what cost; they should also point out what problems have been encountered and how they can be solved.

Reports which may be useful in environmental management for vector control may include annual reports and progress reports relating to major programme events.

Annual and other periodic reports should be issued on time. To stimulate interest in those who furnish them, reports should be processed as rapidly as possible and comments on them should be communicated to the staff concerned for use in programme improvement.

8.2.4 *Information management*

In large projects or in situations involving large volumes of information, the management of the information requires further processing to reduce costs. In such situations a modern management information system may be used. This is a unified integrated comprehensive subsystem of information collection, processing, storage and report generation used for coordinating data from large programme systems, designed to reduce unit costs for information storage and reporting activities. Properly used, management information systems can save managerial and professional time spent on information retrieval and report preparation. They have the potential of unifying fragmented bodies of information coming from different programmes and sources.

Most developing countries may not possess the technological base to keep such systems working. In this instance, the appropriate technology for information handling may still be the traditional techniques of record-keeping and the conventional methods of report preparation. Professional personnel in such countries should nevertheless be aware of the location of management information systems and the services that they offer so that advantage can be taken of these services, particularly in the planning of programmes and in preoperational and postoperational evaluation exercises. One possible source of such information is an encyclopaedia of information systems and services, generally obtainable in major libraries.

8.2.5 *Externally generated information*

Environmental management programmes for vector control need to be buttressed by information generated from other programmes. To facilitate access to such information it is desirable to prepare bibliographies on the subject in general and manuals on various aspects

of the control process. At the international level, a reference centre could be set up, with supporting collaborating centres, of a pattern similar to that of the International Reference Centre on Community Water Supply. Such a centre could play an invaluable role in the collection, indexing and exchange of information. There is a paucity of case-history information for the use of field staff, and international collaboration is called for in preparing suitable documentation.

9. RESEARCH AND DEVELOPMENT

Environmental management measures were applied as basic operations against vectors in disease control programmes in the early years of this century. Their use diminished with the widespread application of pesticides. In recent years, however, attention has once again been focused on them. A review of the existing methods related to environmental management for the control of vectorborne diseases should be carried out.

These methods have already proved their effectiveness, and therefore their reintroduction and expanded use in disease control programmes do not require extensive testing and development. It is, however, essential that they should be assessed in each individual programme for feasibility and cost-effectiveness, as well as in the interests of determining their operational and organizational requirements, before they are put into practice.

The Expert Committee felt that, in order for the results to be conclusive, field trials should be of adequate size and staffed with qualified epidemiologists, entomologists, biologists and engineers, with, where necessary, temporary assistance from sociologists, economists and representatives of other disciplines involved. The Committee also felt that such field trials should be organized in countries in which vector control programmes were in operation as an integral part of those programmes.

A number of problems were reviewed and, in this connexion, the Committee proposed the carrying out of the following studies (not, it should be noted, an exhaustive list):

(1) An extensive study should be performed on intermittent irrigation for the purpose of:

(*a*) determining the effect on vector densities and rice production;

(*b*) identifying irrigation management requirements and procedures;

(*c*) establishing procedures for the coordination of agencies and departments; and

(*d*) studying community participation to ensure continuation of the programme (if successful) by the local community. (The Committee suggested that FAO and WHO should give this study special attention under the terms of the Memorandum of Understanding governing the agencies' collaboration in health aspects of water resources development.)

(2) A field trial of equipment for environmental management should be conducted to study the versatility and applicability of the selected types of equipment for trial, their output rates, operating, maintenance and repair costs and other related parameters.

(3) Studies to improve vector ecology data leading to design criteria for manipulative measures, particularly the following activities:

(*a*) testing the applicability and validity of the "intersection line" value of plants to mosquito (anopheline and culicine) and snail population densities in different biotopes, with special reference to mosquitos at different stages of rice growth;

(*b*) determining critical velocity, depth and dissolved oxygen concentration for suppressing the aquatic larvae of the principal blackfly vector of onchocerciasis;

(*c*) determining the quantitative distribution of mosquitos or snails within irrigation systems—i.e., on-field (the irrigated area) versus off-field (the conveyance system, comprising canals, drains and residual water);

(*d*) collecting data with regard to the breeding of significant mosquito vectors of disease in rice-fields; and

(*e*) determining the lethal drying time for blackfly larvae and snail eggs, at different relative humidities;

(4) Field studies for determining and evaluating the impact of major environmental management measures, with special emphasis on developing a reliable methodology and technique for impact studies.

(5) Case histories of environmental management to be undertaken by a number of national institutes, with international

collaboration, in order to discover the lessons to be learnt from experience with these methods for vector control.

(6) Study of the cost-effectiveness of various methods and materials for canal lining as a method of controlling the aquatic stages of major vectors.

(7) Study of various low-cost materials for plastering rural houses to prevent cracks which might harbour triatomid bugs.

(8) Study of the methods of environmental management which can be carried out and maintained at community level.

(9) Investigation of the nonchemical control of *Mansonia* larvae and the breeding of some culicine mosquitos in plant axils.

10. RECOMMENDATIONS

1. The Expert Committee, recognizing the multidisciplinary character of environmental management for vector control, recommended that close collaboration should be maintained between the United Nations Development Programme, the United Nations Environment Programme, the Food and Agriculture Organization of the United Nations, the World Health Organization, the World Bank, and other international organizations both within and outside the United Nations system, in order to effect:

(*a*) An exchange of information on projects for the development of natural resources (water, agriculture, forestry, etc.).

(*b*) Participation in environmental impact studies, including health aspects, of which the findings should be followed up in project development activities.

A Memorandum of Understanding has already been signed between FAO and WHO and circulated to regional and country offices for implementation. United Nations system organizations concerned should be invited to become party to this agreement and collaborate in the activities it encompasses.

2. At the national level the Expert Committee proposed:

(*a*) The establishment of a coordinating body comprising representatives of governmental agencies involved in health and the development of water and other natural resources. This body would be

responsible for reviewing proposals and plans for these projects and for advising on action to be taken in the prevention and control of vectorborne diseases.

(*b*) The strengthening of collaboration between interested parties at the operational level with respect to joint programming, budgeting and implementation of environmental management measures for the control of vectorborne diseases.

3. In every project that will involve environmental changes, provision should be made for the requisite manpower, material and financial resources to carry out the following activities:

(*a*) Preliminary studies which will permit the selection of the most suitable control methods, taking into consideration such variables as vector biology and human behaviour, which affect transmission.

(*b*) Longitudinal studies and observations for evaluating the degree of success obtained and for ascertaining the improvements required.

(*c*) Application of control operations and their continued maintenance even when incidence and prevalence have been reduced to the target level.

4. Governments, if necessary with the collaboration of international agencies, should review the legislation available for regulating the development and use of natural resources in the light of health and environmental implications, introducing any complementary legal support that might be required.

5. In view of the increasing importance being given to environmental management for vector control, the Expert Committee recommended that:

(*a*) Feasibility studies and cost-effectiveness analyses should be made of different environmental management measures for vector control in order to select the best alternatives to suit given situations.

(*b*) The carrying out of simple, small-scale operations that need the minimum of heavy equipment should be given priority over the implementation of major works.

(*c*) Experimental studies should be made before specialized equipment for environmental management is introduced into large-scale projects.

(*d*) Environmental management should emphasize community involvement and participation at all stages of projects and programmes.

(*e*) Research projects on environmental management technologies should be promoted and supported in different geographical areas by WHO and other international and national agencies. There should be special emphasis on appropriate technology.

(*f*) Appropriate, simple and inexpensive environmental management methodologies for vector control should be integrated without delay into large-scale vectorborne disease control programmes as well as into primary health care systems.

(*g*) Studies of the socioeconomic impact of environmental management measures should be made in order to demonstrate the links between improved health and better socioeconomic conditions.

6. The Expert Committee, recognizing the need for training at all levels for environmental management for vector control, recommended that:

(*a*) University courses related to engineering should include subjects on environmental management for vector control.

(*b*) Environmental management techniques should be included in existing and future national training courses in vectorborne disease control.

(*c*) National development activities, assisted by various international agencies, should be used as a medium for promoting community awareness and for training national staff in the benefits and application of environmental management for the protection and promotion of health.

(*d*) National and international agencies should give urgent consideration to the provision of incentives and openings to encourage the recruitment and retention of personnel required for the planning and implementation of environmental management activities for vector control.

(*e*) Manuals on environmental management for vector control should be prepared for wide dissemination.

(*f*) Information on research, progress and innovations in environmental management techniques for vector control should be collected and widely circulated. In this connexion, the feasibility of establishing an international reference centre for environmental management for vector control should be explored.

(*g*) Seminars, workshops and training courses on environmental management for vector control should be organized in the different regions.

(*h*) Film-strips, tapes and motion pictures should be prepared and made available as training aids. The topics covered should include aquatic weed control, water and land management, irrigation, drainage methods, and insect and rodent control. National and international resources of such training aids should be reviewed and utilized.

7. The Expert Committee noted that the International Drinking-Water Supply and Sanitation Decade was to be launched in 1981 with the objective of providing adequate and safe water supplies and sanitation facilities for all people by 1990, particularly for rural communities in the developing countries. It therefore recommended that, in promoting, planning and implementing projects and programmes for the decade, consideration should be given to the incorporation of environmental management measures for the prevention and control of disease vectors wherever these present an actual or a potential problem.

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Annex 2

CHECKLIST OF MAJOR STEPS FOR THE PREVENTION AND CONTROL OF VECTORBORNE DISEASES AT EACH PHASE OF WATER RESOURCES DEVELOPMENT PROJECTS

Planning phase

(1) Review of existing information on health and related subjects

(*a*) Epidemiology: morbidity and mortality rates, geographical distribution, vector ecology.
(*b*) Health and medical services: facilities, staff, special projects and programmes; degree of development, capacity and coverage.
(*c*) Human population and its characteristics: agricultural, migrant, nomadic, etc.; population growth, importance of migratory movement, displacement within the project area.
(*d*) Cattle: numbers and economic importance, prevalent diseases.
(*e*) Community and housing patterns: location, design, construction materials.
(*f*) Water supply, excreta and wastes disposal facilities.
(*g*) Climatic patterns: temperature, rainfall, humidity, wind, etc.
(*h*) Water: surface water and groundwater, quality, pollution, abundance and seasonal variation, floods and droughts, seasonal variation in temperature.
(*i*) Soil: physical and chemical characteristics, including permeability, stability, salt content, etc.
(*j*) Natural and cultivated aquatic and land vegetation; domestic and wild animals.
(*k*) Economy: national and local, sources and levels of income.
(*l*) Topographical maps: contour lines, roads, villages, etc., of the region and the watershed, design plans of proposed project, etc.

(2) Surveys: To check existing information or fill in gaps in knowledge; assessment and collection of basic data by specialists

(*a*) Detailed epidemiology of major existing diseases and biology and ecology of principal vectors.

(*b*) Health and medical services, disease and vector control programmes and activities, evaluation of effectiveness and resources.

(*c*) Human and cattle movement: migratory currents, their origin and paths.

(*d*) Sanitation: actual and potential sources of water supply, investigation of groundwater sources, actual and potential sources and routes of pollution, practices involving water contact, and methods of excreta disposal, cattle watering and manure disposal.

(*e*) Existing and proposed agricultural crops and practices: irrigation methods, suitable crops, rotation in cultivation and irrigation, use of pesticides and fertilizers, their kind and amount.

(*f*) Local economy: present status and prospects for future development.

(*g*) Sociocultural patterns: present level and possible disturbance produced by the project.

(*h*) Engineering and operational reconnaissance and mapping for ecological, hydrological, and geological or soil studies.

(*i*) Contact with agencies operating in the project area, their type of activities and possibility of assistance and coordination.

(3) Decision-making for the prevention and control of diseases

(*a*) Review of project proposals and preliminary designs and options.

(*b*) Identification of existing health problems.

(*c*) Prediction of possible future problems and of their health effects.

(*d*) Determination of the importance and extent of actual and potential health problems to establish an order of priority in prevention and control operations.

(*e*) Feasibility studies of control measures, including cost-effectiveness and cost-benefit analyses.

(*f*) Selection of village sites and types of water supply and excreta disposal installations.
(*g*) Selection of methods of vector and disease control and estimates of manpower and organizational requirements.
(*h*) Organization of field trials and pilot projects.
(*i*) Settlement of displaced and immigrant population and estimates for the provision of water supply, sanitation and other health facilities.

Design phase

(1) Establishment of design criteria to minimize health hazards and to achieve the objectives of the health programme.

(2) Evaluation of preliminary project designs and alternatives.

(3) Establishment of proposed practices of water-system management and their effects on vector habitats.

(4) Preliminary design and options for canal lining overpasses and other health structures.

(5) Final detailed design of works in the reservoir

(*a*) Shoreline modification and improvement.
(*b*) Clearance and disposal of trees and brush, of man-made structures and fences.
(*c*) Relocation of roads, villages, cemeteries, shrines, etc.
(*d*) Discharge structures sized for water-level regulation and downstream flushing.

(6) Final detailed design of works in irrigation schemes

(*a*) Equalizing reservoirs and night-storage ponds, when necessary.
(*b*) Canals and drains.
(*c*) Regulating structures, gates, sluices, etc., and distributing chambers.
(*d*) On-farm water use.
(*e*) Groundwater use and control.
(*f*) Potential for incorporating domestic water supply.

(7) Final detailed design of measures and works in communities

(*a*) Selection of sites for new communities distant from water sources.

(*b*) Provision of safe, adequate and convenient water supply and sewage disposal systems.

(*c*) Recreation: provision of safe ponds as alternative to infected water bodies, sports grounds, etc.

(d) Other protective measures, such as house-screening, surface-water drainage, general sanitation, and public laundry installations.

(8) Provisions for maintenance activities and their financing.

(9) Environmental management

(*a*) Regulating structures for measurement and control of water discharge and velocity.

(*b*) Gates required for rapid drying and flushing of irrigation subsystems.

(*c*) Adjustment of water salinity in coastal breeding-sites through the installation and operation of gates.

(*d*) Water-level regulation in small reservoirs by means of automatic siphon spillways.

(*e*) Safe crossings and bridges over canals and drains.

(*f*) Lining of canals and drains, closed or subsurface conduits.

(10) Enhancement and simplification of chemical and biological control

(*a*) Design of dispensers for chemical application attached to or incorporated into regulating structures, metal rakes and screens against snails.

(*b*) Access roads and paths for surveillance and spraying, clear water lanes and landings for boats.

(11) Health education of the public and development of community participation.

(12) Health facilities: dispensaries and hospitals.

Construction phase

(1) Health protection of the construction labour force.

(2) Special facilities for disease control and treatment at the construction site.

(3) Adequate housing and sanitary facilities for construction workers and their families.

(4) Surveillance of infections in imported manpower and local population.

(5) Monitoring, vaccination, treatment of local population and elimination and control of endemic diseases, especially those with potential for intensification with project operation.

(6) Environmental protection, erosion, spillage, air and water pollution, disposal of wastes, aesthetic alterations, etc.

(7) Inspection to ensure that construction is carried out according to health designs.

(8) Health education of the public and development of community participation.

Operations phase

(1) Allocation of funds, assignment of staff and impiementation of disease control programmes.

(2) Surveillance, screening and treatment of infected persons.

(3) Establishment of rule curves and schedules for the control of mosquitos, snails, flies, weeds, etc.

(4) Establishment of practices and schedules for water-level regulation.

(5) Maintenance and modernization of structures and other works.

(6) Application of chemical and biological methods for vector and weed control.

(7) Drainage of all water collections around the reservoir.

(8) Prevention and correction of excessive seepage.

(9) On-farm water management.

(10) Operation, maintenance, improvement and development of water supply and sewage disposal systems, general sanitation.

(11) Health education of the public and development of community participation.

(12) Evaluation of vector and disease pattern changes, efficacy of control programmes, study and implementation of amendments or alterations to improve results.

(13) Preparation of periodic and special reports for information purposes.

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